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The SanaViz: Human Centered Geovisualization to facilitate visual exploration of Public Health data

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Dissertation

**The SanaViz: Human Centered Geovisualization to facilitate visual
exploration of Public Health data**

By

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July 18, 2012

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**The SanaViz: Human Centered Geovisualization to facilitate visual
exploration of Public Health data**

A

Dissertation

Presented to the Faculty of
The University of Texas
School of Biomedical Informatics
in Partial Fulfillment
of the Requirements

for the Degree of
Doctor of Philosophy

By

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Ashish Joshi
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DEDICATION

My parents, Late Jatinder Nath Joshi and Rama Joshi, for always believing in me and giving me the support all through my life to pursue my goals and dreams.

My wife Vandana for motivating me to initiate my PhD studies and then support me unconditionally all through this journey.

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TABLE OF CONTENTS

DEDICATION	4
ACKNOWLEDGEMENT	5

TABLE OF CONTENTS

INTRODUCTION	10
---------------------	----

MANUSCRIPTS

A Human Centered Geovisualization framework to facilitate visual exploration of telehealth data: A case study	17
---	----

Designing Human Centered Geovisualization application - the SanaViz - for telehealth users: A case study	41
--	----

Evaluating usefulness and effectiveness of Human Centered GeoVisualization prototype "The SanaViz" to facilitate visual exploration of Telehealth data: A case study	70
--	----

RESEARCH SUMMARY	96
-------------------------	----

List of Illustrations

Manuscript One

Figure 1 Illustration of different components of the Human Centered approach	24
Figure 2 Human Centered GeoVis framework for “The SanaViz”	26
Figure 3 Frequency distribution of spatial skills by gender	31
Figure 4 Frequency distribution of spatial skills by age group	31
Figure 5 Frequency distribution of data dimension by data exploratory role	32

Manuscript Two

Figure 1 Pennsylvania Cancer Atlas (PA-CA)	45
Figure 2 Exploratory Spatiotemporal Analysis Toolkit (ESTAT)	46
Figure 3 Community Health Map (CHM)	46
Figure 4 Instant Atlas	47
Figure 5 Gender frequency stratified by GeoVis interaction	59
Figure 6 Frequency of relevant GeoVis features stratified by prior spatial skills	60
Figure 7 Sketching example	62
Figure 8 Sketching example	62
Figure 9 Frequency of commonly preferred GeoVis features	63
Figure 10 Proposed design of Human Centered GeoVis prototype	65

Manuscript Three

Figure 1 Log in and Registration view of HC GeoVis prototype “the SanaViz”	74
Figure 2 Exploratory analysis view of HC GeoVis prototype “the SanaViz”	75
Figure 3 Results view of HC GeoVis prototype “the SanaViz”	75
Figure 4 Frequency of most common telehealth indicator categories	81

Figure 5 Frequency comparison of task representation for various telehealth categories.

83

Figure 6 Comparing task completion time by GeoVis type and Task

84

Figure 7 Comparing usefulness of Instant Atlas versus the SanaViz

88

List of Tables

Manuscript One

Table 1 Socio-demographic characteristics of the study participants	29
--	----

Table 2 Users' perception towards exploration of telehealth data	30
---	----

Manuscript Two

Table 1 System Usability Scores for various GeoVis applications	51
--	----

Table 2 Card sorting results	55
-------------------------------------	----

Table 3 Card sorting analysis stratified by user category	57
--	----

Table 4 Relevant Interaction and representation features by diverse users	58
--	----

Manuscript Three

Table 1 Number of tasks among various telehealth indicator categories	82
--	----

Table 2 Individual comparisons for time by tasks and GeoVis applications	83
---	----

Table 3 Individual statistical tests for ease by GeoVis applications and tasks	85
---	----

Table 4 Individual comparisons for assistance by tasks	86
---	----

INTRODUCTION

Background and Motivation

Public health data is typically organized at a geospatial unit and often has 3 dimensions: (a) attribute (i.e., context), (b) spatial (i.e., geographic) and (c) temporal (i.e., time) (Rivest, Bedard, & Marchand, 2001; Jamison, 2006). Attribute (context) component relates to public health issues of interest such as social and environmental data. Spatial (geographic) component includes data with location attributes (e.g. address, region, or country) and can provide insight into how and where to obtain important services such as healthier food, improved transportation, remote consultations, and low-cost exercise facilities (Richards, Croner, Rushton, Brown, & Fowler, 1999). Temporal (time) component records time of the observation and enables users to learn from the past to predict, plan, and build the future (Aigner, Miksch, Mueller, Schumann, & Tominski, 2007). To improve public health, researchers often examine complex, multidimensional data that enables them to identify patterns, thereby assembling meaningful information (Rivest et al., 2001; Jamison, 2006) and this multidimensional analysis tends to be more in agreement with the end user's mental model. As public health datasets become increasingly complex, there is a growing need for methods and tools to support the construction of knowledge (Bhowmick, Griffin, MacEachren, Kluhsman, & Lengerich, 2008).

Visual representations can often communicate information much more rapidly and effectively and help decision makers prioritize the actions and regulations required for better public health outcomes (Malczewski, 2006). GeoVisualization (GeoVis) is described as the use of visual geospatial displays to explore data, generate hypotheses, develop problem solutions, and construct knowledge. GeoVis simplifies large and complex datasets into more comprehensible forms and allow users to see the information visually on a map that is otherwise hidden in the complexity of the data. Maps are an efficient means for communication, analysis, synthesis, and exploration, of geographic data and information (van Elzakker, 2003). Maps in GeoVis environment are used to stimulate visual thinking about geospatial patterns, relationships and trends.

GeoVis is increasingly being used to inform public health research, planning and decision making (Cinnamon et al., 2009). However, despite the applicability of GeoVis in public health, GeoVis tools are still underused (Bhowmick et al., 2008). Limited guidance exists on how to actually design simple, functional GeoVis applications for use in the public health realm (Robinson, Chen, Lengerich, Meyer, & MacEachren, 2005). Prior studies have shown limited

focus on domain specific considerations with end user input often was incorporated only after key functionality and interface design issues were decided. GeoVis applications are difficult to learn and use, are predominantly generic, do not address specific users and are designed according to the engineering and technology principles (Robinson et al., 2005). A Human Centered (HC) GeoVis is needed to facilitate visual exploration of public health data.

Theoretical framework

The HC approach gives specific considerations to users' knowledge, expertise and use of the interaction techniques to represent tasks performed by the users (Andrienko et al., 2007; Koua & Kraak, 2004; Hollan, Hutchins, & Kirsh, 2000; Zhang & Butler, 2007). Processing of different types of information will be affected by what type of visual display is used to present that information. When the information presented does not match ultimate needs of the task, it results in decreased accuracy and increased time (Dennis & Carte, 1998). These benefits translate into system and task related performance factors. Cognitive fit theory (CFT) explains how graphical displays affect the decision processes and depends upon fit between information presentation and tasks used by decision maker (Dennis & Carte, 1998). The HC GeoVis approach combines principles of cognitive science, geography, computer science, public health literature review, and knowledge drawn from our previous studies in the U.S. and Brazil (Joshi & Hsu, 2010; Joshi, Zhang, Hsu, & Parvizi, 2010; Joshi et al., 2011).

Objective

The objective of the proposed research is to use the HC approach to design and develop a domain specific, data driven HC GeoVis prototype tailored to the needs of the Teleeducation (TE) users, their tasks and preferences (Andrienko et al., 2007).

Study Methods

The prototype will be evaluated among the first time in the field of TE in developing countries, specifically Brazil. Public health system is usually the major provider of healthcare services in developing countries and is typically organized at geospatial units. The healthcare resources are limited, and there is an unequal geographical distribution of healthcare professionals limiting the outreach of healthcare to the populations. TE involves the use of educational technologies to connect geographically dispersed healthcare professionals. TE has been proposed as one of the solutions to healthcare problems in developing countries; however, *a major challenge with TE adoption in developing countries is lack of evaluation data.*

The NUTES telehealth centre, Recife coordinates the telehealth program in the State of Pernambuco, Brazil. Telehealth program at NUTES facilitates delivery of Teleeducation (TE) sessions to various primary health care centres in Pernambuco state. TE sessions of one hour duration occur four times a week and include healthcare professionals from all specialties. TE sessions are live and interactive, typically consisting of a 30 min presentation in the form of slides and videos followed by a 30 min question-and-answer session. After each session, participants complete an evaluation questionnaire reflecting their feedback about the technology, the healthcare specialist delivering the session and the educational content.

Specific Aims

The specific aims and associated research questions for the proposed HC GeoVis prototype research are:

Specific Aim #1: To design GeoVis prototype for exploratory data analysis (EDA) of public health data using HC approach.

- This cross sectional, mixed methods study is a proof of concept to explore the utilization of GeoVis to evaluate a telehealth program in Brazil. The GeoVis proposed framework integrates principles of public health, human centered approach and cognitive fit theory to help us develop greater understanding about the telehealth users. The study found that telehealth users had varied roles and responsibilities and came back from diverse backgrounds. There was strong motivation and relevance among the telehealth users to utilize GeoVis despite having no or minimal spatial skills. The information was essential to design GeoVis application, “the SanaViz”, with due knowledge and information structure to match those of the telehealth users.

Specific Aim #2: To develop GeoVis prototype for exploratory data analysis (EDA) of public health data using HC approach.

Twenty similar subjects from aim # 1 were enrolled to conduct in-depth interviews, card sorting and sketching methods in order to gather feedback about the necessary components that were essential to be part of the Web-based HC GeoVis application “the SanaViz” to facilitate visual exploration of telehealth data.

Specific Aim #3: To evaluate HC GeoVis prototype “the SanaViz” to assess TE program in developing countries, specifically Brazil as compared to conventional GeoVis application.

A case study was discussed in-depth on similar subjects from aim # 2 to determine usefulness and effectiveness of HC GeoVis prototype “the SanaViz” as compared to conventional GeoVis application.

These three manuscripts are presented as a PhD dissertation for the study of using GeoVis application to evaluate telehealth programs. The primary reason of this research was to understand how the GeoVis applications can be designed and developed using combined approaches of HC approach and cognitive fit theory and in terms utilized to evaluate telehealth program in Brazil.

First manuscript

The first manuscript in this dissertation presented a background about the use of GeoVisualization to facilitate visual exploration of public health data. The manuscript covered the existing challenges that were associated with an adoption of existing GeoVis applications. The manuscript combines the principles of Human Centered approach and Cognitive Fit Theory and a framework using a combination of these approaches is developed that lays the foundation of this research. The framework is then utilized to propose the design, development and evaluation of “the SanaViz” to evaluate telehealth data in Brazil, as a proof of concept.

Second manuscript

The second manuscript is a methods paper that describes the approaches that can be employed to design and develop “the SanaViz” based on the proposed framework. By defining the various elements of the HC approach and CFT, a mixed methods approach is utilized for the card sorting and sketching techniques. A representative sample of 20 study participants currently involved in the telehealth program at the NUTES telehealth center at UFPE, Recife, Brazil was enrolled. The findings of this manuscript helped us understand the needs of the diverse group of telehealth users, the tasks that they perform and helped us determine the essential features that might be necessary to be included in the proposed GeoVis application “the SanaViz”.

Third manuscript

The third manuscript involved mix- methods approach to compare the effectiveness and usefulness of the HC GeoVis application “the SanaViz” against a conventional GeoVis application “Instant Atlas”. The same group of 20 study participants who had earlier participated during Aim 2 was enrolled and a combination of quantitative and qualitative assessments was done. Effectiveness was gauged by the time that the participants took to complete the tasks using both the GeoVis applications, the ease with which they completed the tasks and the

number of attempts that were taken to complete each task. Usefulness was assessed by System Usability Scale (SUS), a validated questionnaire tested in prior studies. In-depth interviews were conducted to gather opinions about both the GeoVis applications. This manuscript helped us in the demonstration of the usefulness and effectiveness of HC GeoVis applications to facilitate visual exploration of telehealth data, as a proof of concept.

Together, these three manuscripts represent challenges of combining principles of Human Centered approach, Cognitive Fit Theory to design and develop GeoVis applications as a method to evaluate Telehealth data. To our knowledge, this is the first study to explore the usefulness and effectiveness of GeoVis to facilitate visual exploration of telehealth data. The results of the research enabled us to develop a framework for the design and development of GeoVis applications related to the areas of public health and especially telehealth. The results of our study showed that the varied users were involved with the telehealth program and the tasks that they performed. Further it enabled us to identify the components that might be essential to be included in these GeoVis applications.

The results of our research answered the following questions; (a) Telehealth users vary in their level of understanding about GeoVis (b) Interaction features such as zooming, sorting, and linking and multiple views and representation features such as bar chart and choropleth maps were considered the most essential features of the GeoVis applications. (c) Comparing and sorting were two important tasks that the telehealth users would perform for exploratory data analysis. (d) A HC GeoVis prototype application is more effective and useful for exploration of telehealth data than a conventional GeoVis application.

Future studies should be done to incorporate the proposed HC GeoVis framework to enable comprehensive assessment of the users and the tasks they perform to identify the features that might be necessary to be a part of the GeoVis applications. The results of this study demonstrate a novel approach to comprehensively and systematically enhance the evaluation of telehealth programs using the proposed GeoVis Framework.

References

- Aigner, W., Miksch, S., Mueller, W., Schumann, H., & Tominski, C. (2007). Visualizing time - oriented data: A systematic review. *Computers and Graphics*, 31, 401-409.
- Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M. J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, 21(8), 839-857.
- Bhowmick, T., Griffin, A. L., MacEachren, A. M., Kluhsman, B. C., & Lengerich, E. J. (2008). Informing geospatial toolset design: Understanding the process of cancer data exploration and analysis. *Health & Place*, 14(3), 576-607.
- Cinnamon, J., Rinner, C., Cusimano, M. D., Marshall, S., Bekele, T., Hernandez, T., . . . Chipman, M. L. (2009). Evaluating web-based static, animated and interactive maps for injury prevention. *Geospatial Health*, 4 (1), 3-16.
- Dennis, A. R., & Carte, T. A. (1998). Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations. *Information Systems Research*, 9(2), 194-203.
- Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 7(2), 174-196.
- Jamison, D. T. (2006). Disease control priorities in developing countries. Washington, DC: Oxford University Press.
- Joshi, A., & Hsu, E. (2010). Application of spatial methods in identifying geographic variations in populations with chronic diseases: A critical review. Proceedings from the 138th American Public Health Association. Denver, CO.
- Joshi, A., Novaes, M.A., Iyengar, S., Machiavelli, J.L., Zhang, J., Vogler, R., & Hsu, E. (2011). Evaluating participant satisfaction perspective towards teleeducation services in Brazil: *Journal of Telemedicine and Telecare*, 17(7), 341-345.
- Joshi, A., Zhang, J., Hsu, E., & Parvizi, J. (2010). Exploratory analysis on the visualization of temporal utilization of total joint arthroplasty in 2000-2008. Proceedings from the 12th Brazilian Congress of Health Informatics. Porto de Galinhas, Brazil.
- Koua, E. L., & Kraak, M. J. (2004). A usability framework for the design and evaluation of an exploratory geovisualization environment. Proceedings from the 8th International Conference on Information Visualization. London, UK: IEEE Computer Society.

- Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, 20 (7), 703-726
- Richards, T. B., Croner, C. M., Rushton, G., Brown, C. K., & Fowler, L. (1999). Geographic information systems and public health: Mapping the future. *Public Health Reports-US*, 114, 359-373.
- Rivest, S., Bedard, Y., & Marchand, P. (2001). Toward better support for spatial decision making: Defining the characteristics of spatial on-line analytical processing (SOLAP). *Geomatica*, 55(4), 539-555.
- Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., & MacEachren, A. M. (2005). Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science*, 32(4), 243.
- van Elzakker, C. P. J. M. (2003). The use of maps in exploration of geographic data. Proceedings from the 21st International Cartographic Conference (ICC). Durban, South Africa.
- Zhang, J., & Butler, K. (2007). UFuRT: A work-centered framework and process for design and evaluation of information systems. Proceedings from the 12th International Conference, HCI International 2007. Beijing, China.

MANUSCRIPTS

A Human Centered Geovisualization framework to facilitate visual exploration of telehealth data: A case study

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Key words: GeoVisualization; Human Centered; Public health; Cognitive Fit theory; Telehealth

Abstract

Public health data is typically organized by geospatial units. Routine geographic monitoring of health data enables an understanding of the spatial patterns of events in terms of causes and controls. GeoVisualization (GeoVis) allows users to see hidden information both visually and explicitly on a map. Despite the applicability of GeoVis in public health, it is still underused for visualizing public health data. The objective of this study is to examine the perception of telehealth users' to utilize GeoVis as a proof of concept to facilitate visual exploration of telehealth data in Brazil using principles of human centered approach and cognitive fit theory. A mixed methods approach was utilized in this cross sectional study conducted at the Telehealth Center of the Federal University of Pernambuco (NUTE-UFPE), Recife, Brazil. A convenient sample of 20 telehealth participants was drawn during a period of Sep-Oct 2011. Data was gathered using previously tested questionnaire surveys and in-person interviews. Socio-demographic Information and prior familiarity with the use of computer and GeoVis was gathered. Other information gathered included participants' prior spatial analysis skills, level of motivation and use of GeoVis in telehealth. Interviews were recorded both in English and Portuguese. Transcription of the audio content to English was done by a certified translator. Univariate analysis was performed for the continuous and categorical variables. For the open-ended questions, we utilized a grounded theory to identify themes and their relationship as they emerge from the data. Analysis of the quantitative data was performed using SAS V9.1 and qualitative data was performed using NVivo9. The average age of participants was 28 years (SD=7) and a majority of them were females. The users had diverse roles and backgrounds and were most familiar with Google maps. Despite having minimal spatial skills, there was a strong motivation and relevance among the telehealth users to use GeoVis to facilitate visual exploration of telehealth data. Results showed users' preference for analyzing both spatial and temporal dimensions of the data. Maps were the first choice to represent the data as it will be able to display the events both in place and time. Understanding of users' needs is essential to ensure that the technology is appropriately functional and will be useful to complete the tasks.

Introduction

Illness and health are distributed unequally across space and time while the latter can be vital but often neglected in the assessment of health issues (Braveman & Tarimo, 2002). Public health data is typically organized by geospatial units and has 3 dimensions: (a) attribute (i.e., context), (b) spatial (i.e., geographic) and (c) temporal (i.e., time) (Rivest, Bedard, & Marchand, 2001; Jamison, 2006). Attribute (context) component relates to public health issues of interest such as social and environmental data. Spatial component includes data with location attributes (e.g. address, region, or country). Understanding how place relates to public health and health care is important in order to deliver effective interventions. It can provide insight into where to obtain important services such as better food, improved transportation, remote consultations, and low-cost exercise facilities (Richards, Croner, Rushton, Brown, & Fowler, 1999). Temporal component records time of the observation and enables users to learn from the past to predict, plan, and build the future (Aigner, Miksch, Mueller, Schumann, & Tominski, 2007). Routine monitoring of health data with a geographic context enables an understanding of the spatial patterns of disease, helps healthcare providers to identify who and where the people are most likely to be affected by disadvantaged neighborhood environments and identify the geographical distribution of insufficient health workers particularly in rural and remote areas (Lee & Irving, 1999). Similarly temporal change in geography enables to describe trends (Haggett, 1990; Edsall & Sidney, 2005). Telehealth data could represent a case scenario of public health data where the telehealth site includes spatial component, the time when the sessions are conducted becomes the temporal component and the attribute component can be reflected by the types of telehealth sessions, their duration, technical problems associated with each session or overall acceptance of the sessions.

Public health system is usually the major provider of services in developing countries and is typically organized by a geospatial unit. Limited technology infrastructure, financial constraints, maldistribution of health-care professionals and healthcare facilities are some of the major challenges to provide quality care. Telehealth is one of the solutions to address the healthcare problems. It is defined as the use of electronic information and telecommunication technologies to support long-distance clinical health care, patient and professional health-related education, public health and health administration (Dasgupta & Deb, 2008). Telehealth can be useful to provide access to healthcare for rural and underserved, home care and provider education.

Timely evaluation of telehealth programs is pivotal to assess if the resources are allocated appropriately to improve the delivery of healthcare services especially in remote and rural settings. Limited evaluation of telehealth programs in developing countries has been one of the reasons of their poor adoption. Other barriers to the implementation of telehealth were Internet congestion causing delays or a low frame rate of the video pictures and interruptions and delays in voice transmission, and untrained service providers including physicians and staff (Liou, Chen, Hsu, Chou, & Chiu, 2006; Yip, Mackenzie, & Chan, 2002; Kawasaki et al., 2003; Brandling-Bennett et al., 2005; Lattimore Jr, 1999). It is very important for telehealth to be evaluated aggressively on a continuing, appropriate and comprehensive basis (Adams, McCall, Gray, Orza, & Chalmers, 1992). Lack of telehealth service indicators for managers also reflects a need of GeoVis. The current study addresses this important gap by proposing GeoVis as a proof of concept to evaluate telehealth program.

As public health datasets become increasingly complex, there is a growing need for developing methods and tools to support the construction of knowledge (Bhowmick, Griffin, MacEachren, Kluhsman, & Lengerich, 2008). Public health organizations are increasingly harnessing geospatial technologies to aid in decision support for a broad array of services including disease surveillance, health services allocation and health promotion initiatives. Visual representations can often communicate information much more rapidly and effectively and can help decision makers prioritize the actions and regulations required for better public health outcomes (Malczewski, 2006).

Geovisualization (GeoVis) is defined as the use of visual geospatial displays to explore data, to generate hypotheses, develop problem solutions, and construct knowledge (Cinnamon et al., 2009). GeoVis simplifies large and complex datasets into more comprehensible forms and allow users to see otherwise hidden information, both visually and explicitly, on a map. GeoVis is used to inform public health research, planning and decision making (Cinnamon et al., 2009). Mapping and GeoVis applications are increasingly being integrated into public health information systems. Maps are an efficient means for the communication, analysis, synthesis, and exploration, of geographic data and information (van Elzakker, 2003). Maps in GeoVis environment are used to stimulate visual thinking about geospatial patterns, relationships and trends. However, despite the applicability of GeoVis in public health, GeoVis applications are still underused (Bhowmick et al., 2008). Limited guidance exists on how to actually design simple, functional GeoVis applications for use in the public health realm (Robinson, Chen, Lengerich, Meyer, & MacEachren, 2005).

Role of GeoVis applications in Public Health

Increasingly complex public health datasets reflect a growing need for methods and tools to support the construction of knowledge (Cinnamon et al., 2009). Knowledge can be created and revealed through abstract representations of maps (Jamison, 2006). In this case, GeoVis interaction helps in gaining new insights rather than just communicating something that is already known. GeoVis can be used to inform public health research, planning, and decision making (Cinnamon et al., 2009) and are being increasingly integrated into public health information systems to:

- Create maps to support evidence-based public health planning and research (Cinnamon et al., 2009).
- Examine distribution of disease (Chen, Yi, & Mao, 2008) and injury (Schuurman, Cinnamon, Crooks, & Hameed, 2009).
- Study risk factors (Wang, Hu, & Tong, 2009).
- Examine effectiveness of disease control and policies (Castillo-Riquelme, 2008).
- Identify problems of access, quality, and the safety of healthcare (Castillo-Riquelme, 2008).
- Represent complex and large volumes of birth defects data (Gebreab, Gillies, Munger, & Symanzik, 2008).
- Solve problem of potential locational inequities in accessibility to dental care (Horner & Downs, 2008).
- Map cancer statistics to inform policymakers and the public (Bhowmick et al., 2008).
- Visualize community health disparities (Robert & Ellen, 2009) for planning and resource allocation in developing countries (Parmanto et al., 2008).

In summary, GeoVis displays events in space and time, making possible the perception of where and when events occurred. GeoVis applications can be useful in displaying these variations so that targeted interventions can be planned in a timely manner. The following section discusses current GeoVis applications in public health and its associated limitations.

Existing Public Health GeoVis applications and associated challenges

Pennsylvania Cancer Atlas (PA-CA), an interactive online atlas, helps policy-makers, program managers, and epidemiologists with tasks related to cancer prevention and control (Bhowmick, Robinson, Gruver, MacEachren, & Lengerich, 2008). Similarly Exploratory Spatiotemporal

Analysis Toolkit (ESTAT) (Robinson, 2005) is designed to provide cancer researchers with visual tools to explore multivariate spatiotemporal data. Community Health Map (CHM) (Sopan et al., 2005) web application enables users to visualize health care data in multivariate space as well as geospatially. It is designed to aid exploration and deliver deep insights for policy makers, consumer groups and academic researchers. The application supports tasks incorporating the use of filter, interactive map, table and chart. Instant Atlas (van der Wilk & Verschuuren, 2010) enables information analysts and researchers to create highly-interactive dynamic and profile reports that combine statistics and map data to improve data visualization, enhance communication, and engage people in more informed decision making. A result of another previous study where GeoVis application Interactive Map Tool (IMT) (Cinnamon et al., 2009) was used indicates that different map types are useful for different purposes and for satisfying the varying individual skill level.

Results of the prior studies showed lack of a number of the essential ingredients needed to make use of the existing GeoVis applications by typical public-health researchers (Muntz et al., 2003). The need to assess the usefulness and usability of GeoVis applications is increasing as new types of interactions emerge (Muntz et al., 2003). It is essential to focus on the effectiveness, usefulness and performance of GeoVis applications. This is needed because use and usability testing can provide insight into how a visual interface can support data-exploration tasks. However, prior studies have shown that a majority of existing GeoVis applications are designed according to the technology and software engineering principles. Recently, there was a shift towards user-centered design (Fuhrmann et al., 2003; Timpka, Ölvander, & Hallberg, 2008). Domain specific considerations have been overlooked and end user input has been incorporated only after key functionality and interface design issues have been decided. GeoVis applications are difficult to learn and use, are predominantly generic and do not address specific users (Robinson et al., 2005). This has elicited the following questions such as (a) are new GeoVis methods appropriate for the target user group? (b) Are they useful for the user's purposes? (c) How can the user contribute to the design of new technologies and (d) what level of user needs assessment is required? Better GeoVis applications can be created through a usability approach and with knowledge of cognitive processes (Slocum et al., 2001).

The overall objectives of the study are to construct GeoVis application the "SanaViz" using combined principles of Human Centered approaches (HC) and Cognitive Fit Theory (CFT) to facilitate visual exploration of telehealth data. The aim of the study is to design GeoVis application "the Sanaviz" for exploratory data analysis (EDA) of telehealth data using HC

approach. This paper discusses a pilot study that examines various users that are involved with the telehealth program, their expertise and skills and their perception towards the utilization of GeoVis to evaluate telehealth program. The other aims will be discussed in subsequent papers. To our knowledge, this is the first study to explore the role of GeoVis to facilitate the visual exploration of telehealth data.

Theoretical framework

The International Cartographic Association Commission on Visualization and Virtual Environments (ICACVVE) met to identify a research agenda for GeoVis and the key focus that evolved was to develop an HC approach to GeoVis (ISO, 1999; Dix, Finlay, Abowd, & Beale, 1998).

(i) Human Centered approach (HC): The principles of HC approach involve (Fuhrmann et al., 2003) (Fig1);

- Active involvement and understanding of users
- Understanding task requirements
- Appropriate allocation of function between user and system
- Iteration of design solutions
- Multidisciplinary design teams

Understanding users is an important aspect for creating GeoVis applications. Individual's ability to work with GeoVis applications depends upon their age, education, prior spatial skills, and familiarity with computer expertise (Slocum et al., 2001). The user model helps to gather individuals' understanding about data, functions, domain and mapping (Lauesen, 2005). Mapping understanding of user needs to the system functions is necessary to create a useful and effective GeoVis application (Lauesen, 2005). However, role of users in GeoVis has been limited (Evans, 1997; McGuinness, 1994). User-characteristics and preferences are often overlooked. Uptake of GeoVis applications has been slow and fully understanding users, their needs and their requirements to meet particular tasks is needed well before the design of GeoVis applications. HC approach involves users' perspective in order to create a system that is useful and useable. An important first step in understanding how to design better GeoVis interactions is to understand user tasks and goals. The geographic analysis process can be viewed as a set of tasks and operations need to meet the goals of the data exploration, gain insight and knowledge construction (Fleishman, Quaintance, & Broedling, 1984; Gahegan, Wachowicz, Harrower, & Rhyne, 2001). The tasks involve a number of specific activities and

operations that users will perform for exploratory data analysis (EDA) (Walton, 1996). Tasks classification has shown to create useful GeoVis applications. In a prior study, set of user tasks that users might perform in a visual environment include locate, identify, distinguish, categorize, distribute, compare and correlate among several variables (Wehrend & Lewis, 1990). The basic premise of exploratory GeoVis is that insight is formed through interaction. Interactivity facilitates exploration, hypothesis generation in a more effective and dynamic manner (Crampton, 2002). Interactivity in GeoVis changes visual data display in response to user input (Crampton, 2002). Interactions in GeoVis (a) allow users directly control the display of data, (b) are a fundamental part of how maps and mapping tools are used and (c) compares and critiques different mapping environments. GeoVis interactions enable users to derive meaning and accomplish various analysis goals. Interactivity in GeoVis can have multiple levels (a) Lower level interaction involves comparisons made by viewing two or more maps simultaneously in separate windows. (b) Medium level interactivity includes viewing and browsing activities such as user-defined selection of map area or scale, zoom level or scrolling across the map. This includes (i) Ordering Data e.g. classification and using color schemes to mark different phenomenon and (ii) sorting spatial data e.g. data can be displayed dynamically by varying the threshold for association between variables. (c) High level of user interactivity is designed to support spatial thinking i.e. hypothesis generation, data analysis and decision making and includes (i) extraction e.g. highlight and (ii) filtering e.g. brushing and dynamic data manipulation (Crampton, 2002). Processing of different types of information will be affected by what type of visual display is used to present that information and hence providing different perspectives of the data. (Figure 1)

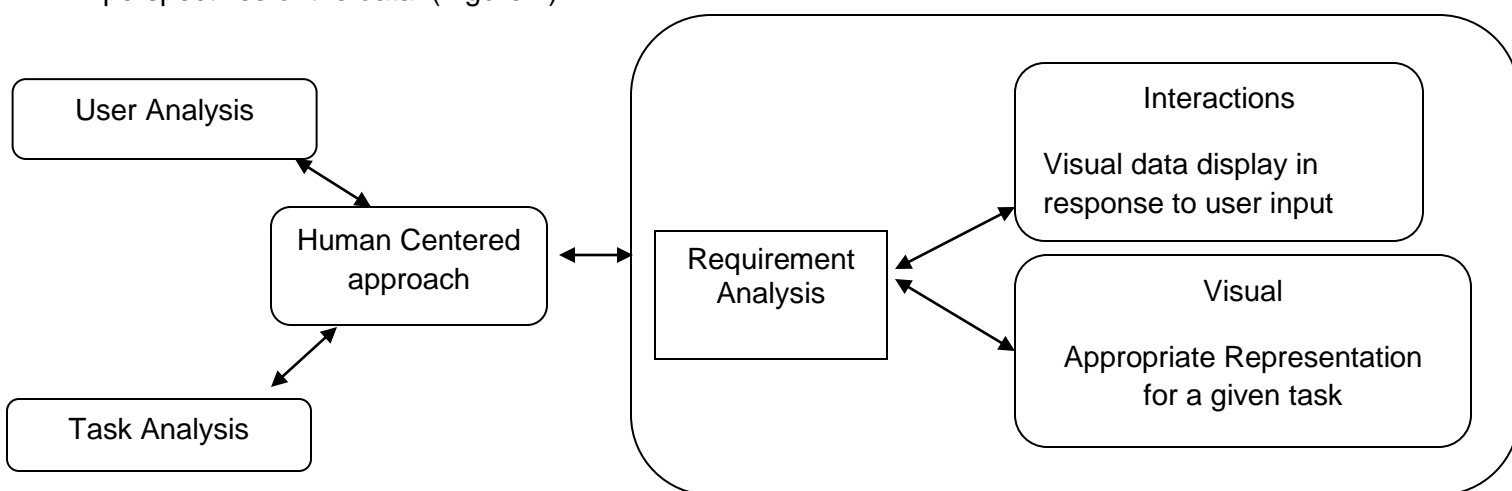


Figure 1. Illustration of different components of the Human Centered approach

When the information presentation matches the task, it produces faster and more accurate results (Joshi et al., 2011). These benefits translate into system and task related performance factors. Cognitive fit theory (CFT) explains how graphical displays affect the decision processes (Dennis & Carte, 1998). CFT depends upon fit between information presentation and tasks used by decision maker. Cognitive fit identifies an appropriate representation for a given task performed by users (Dennis & Carte, 1998). Task type distinctions and combinations might reveal that one representation is favored over the other. Prior study has shown that information presentation format is the primary factor influencing decision processes (Dennis & Carte, 1998). Choice of an interaction method and representation is crucial to the success of a GeoVis environment. Therefore combining the principles of HC approach and Cognitive Fit Theory (CFT) will facilitate the development of “the SanaViz”, a GeoVis application to evaluate telehealth program (Figure 2).

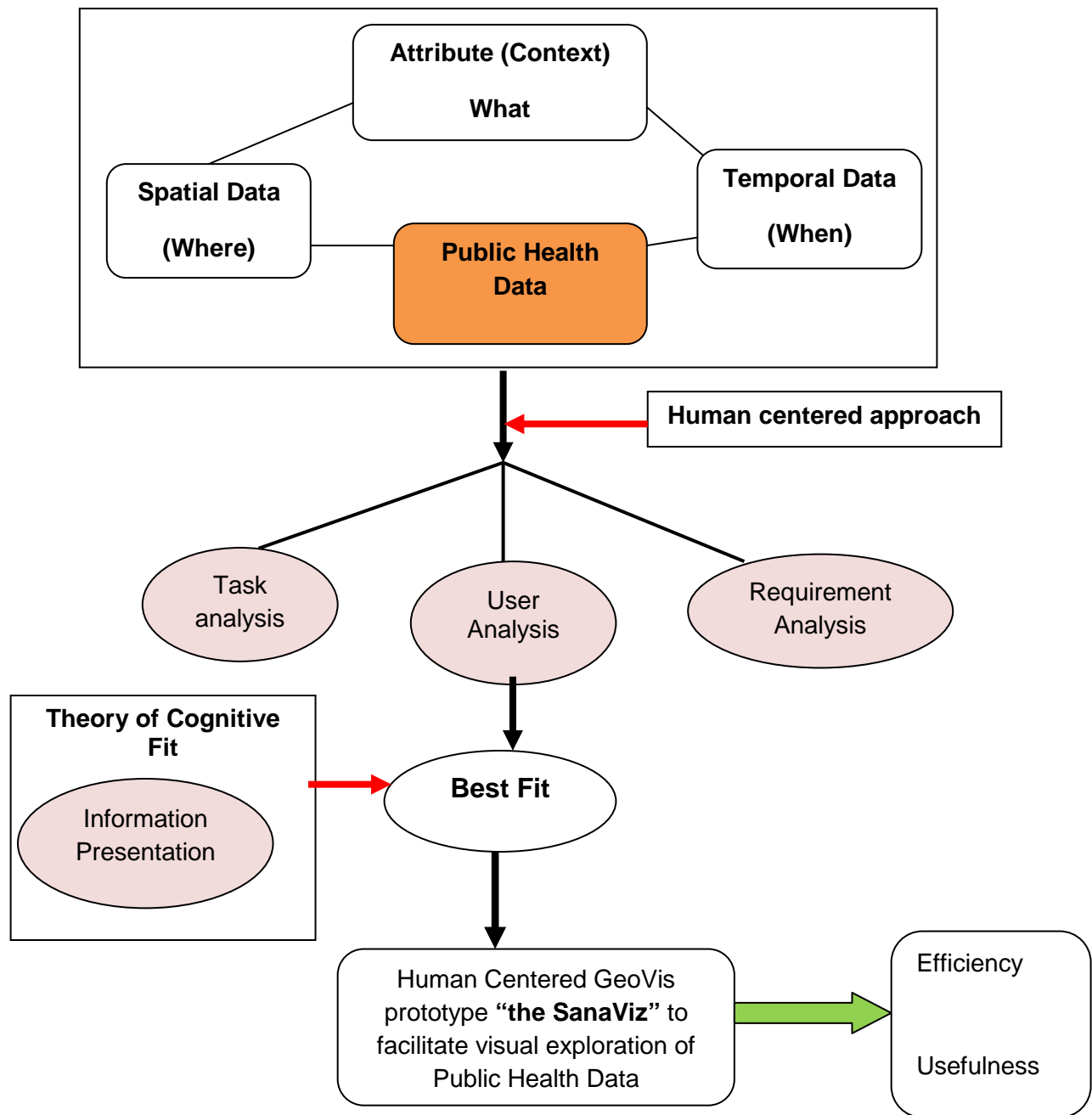


Figure 2. Human Centered GeoVis framework for "the SanaViz"

Methods

Study design and study setting

A cross sectional study design using a mixed methods approach, combination of qualitative and quantitative assessments was employed. The study setting was the Telehealth Center at the Federal University of Pernambuco (NUTES-UFPE), Recife, Brazil. The Brazilian eHealth program is aimed to improve the quality of care delivered at the primary health units to minimize unnecessary removal of patients and inadequate referrals to the large hospitals. The program aims to provide basic health assistance to poor population in its own communities.

RedeNUTES is a network of centers of Telehealth that develops telehealth for health program (PSF) (Parmanto et al., 2008). This project is linked to Brazilian eHealth program and coordinated by NUTES-UFPE. The first phase of RedeNUTES began in 2003, with teleeducation activities and tele-assistance for four municipalities of the metropolitan area of Recife and now provides these services to more than 200 health centers at various locations. A convenient sample of 20 participants currently involved in the NUTES-UFPE, were enrolled for this pilot study. Selection of the sample size ($n=20$) was based on recommendations from usability engineering literature (Nielsen & Landauer, 1993; Kushniruk, Patel, & Cimino, 1997). This study was approved by the University of Texas Health Science Center Institutional Review Board.

Procedure

The study participants were given a brief presentation about the purpose of the study. This was followed by an introduction on GeoVis followed by a demonstration of an example scenario describing use of GeoVis to facilitate visual exploration of public health data using existing GeoVis applications. Study participants were asked to fill in both open-ended and close-ended questionnaires.

Data gathering techniques: Data gathering approaches included questionnaires and interviews.

Socio-demographic characteristics: Information gathered included age (years), gender (male/female), prior education, familiarity with the use of computer (very familiar/somewhat familiar/less familiar/not familiar at all) and GeoVis application (regular user/sometimes/occasional/rarely/never).

Questionnaire: A questionnaire used in an earlier study was used to conduct user analysis (Valiati, Freitas, & Pimenta, 2008). Information was gathered about participants' involvement

with the amount of data (no real data/limited real data/moderate real data/extensive real data), data dimension (attribute related/temporal related/spatial related/spatiotemporal related), data exploration (no exploratory role/ basic exploratory role/moderate exploratory role (large exploratory role), spatial skills (nor minimal spatial skills/use maps but use others for GIS skills/basic GIS skills for spatial analysis/advanced GIS skills for spatial analysis), GeoVis motivation (no motivation/minimal motivation/moderate motivation/strong motivation) and GeoVis relevance (no relevance/minimal relevance/moderate relevance/strong relevance).

Interviews: Interviews comprised of open and closed-ended questions and were conducted to assess the perspective of the users towards utilization of GeoVis to facilitate visual exploration of telehealth data. Feedback was also gathered about participants' prior experience of viewing data in maps, plots and tables, prior use of GeoVis for analyzing telehealth data. Feedback was also gathered to understand the participants' feedback about level of granularity at which results should be presented, stakeholders who could get the possible benefits of using GeoVis application and the possible challenges that the participants would possibly come across during the use of GeoVis applications. Audio recording was done for the interviews in both English and Portuguese. Audio files were then transcribed into notes by a Certified Portuguese to English translator.

Statistical Analysis

Univariate analysis was performed to report means and standard deviation for continuous variables while frequency analysis was reported for the categorical variables as appropriate. For the open-ended questions, we employed grounded theory to identify themes and their relationships as they emerge from the data. This analytical approach provided the flexibility to explore the meaning of narrative data while providing a rigorous methodology [20]. All quantitative data was analyzed using SAS v 9.1 and qualitative data was analyzed using NVivo software.

Results

A convenient sample of twenty subjects from diverse categories of the telehealth program at the NUTES Telehealth Center at UFPE was enrolled during Sep-October 2011. The average age of the participants was 28 years (SD=7), majority of them were females and 90% of them were graduate professionals while the 10% were statistics students. The users had diverse backgrounds including nursing, computer sciences, biomedical informatics, statistics, dentistry, administration and engineering. Almost 100% of the professionals were somewhat to very familiar with the use of computers. Only 5% were of them were familiar with use of GeoVis

applications. Google maps were the most common GeoVis application that the users were familiar with (Table 1).

Variables	Results
Age, years	Mean=29; SD=7
Female	65%
Education, Graduate	90%
Computer familiarity, Very familiar	80%
Familiarity with use of GeoVis applications; Occasional	35%
Never	45%
Users' background	
Software programmer	20%
Healthcare professionals	25%
Project manager	15%
Computer system analyst	10%
Health informatics researchers	15%
Other, please specify	Administrator 5% Telehealth Attendant 5% Telehealth Training Assistant =5% Statistics =5%

Table 1. Socio-demographic characteristics of the participants enrolled in the current study

Results also showed that a majority of the participants worked with extensive real data and described spatiotemporal data as the most important data dimension. The participants indicated that representation of an event's location and time are both relevant for better understanding of the data. The participants' role in exploring the data varied from basic to large exploratory in nature. Despite the majority of the participants having no or minimal spatial skills, they were highly motivated and considered GeoVis to evaluate telehealth programs as highly relevant (Table 2).

Variables	Frequency (%)
Amount of Data	
Limited experience working with real data	10
Moderate experience working with real data	50
Extensive experience working with real data	40
Data Dimension	
Attribute related	35
Spatiotemporal related	60
Attribute and temporal	5
Data Exploration	
No exploratory role	5
Basic exploratory role	50
Moderate exploratory role	10
Large exploratory role	35
Spatial skills	
No or minimal spatial skills	70
Use Maps but use others for GIS skills	15
Basic GIS skills for spatial analysis	15
GeoVis Motivation	
Moderately motivated	15
Highly motivated	85
GeoVis Relevance	
Moderate relevance	10
Strong relevance	90

Table 2. Users' perception towards exploration of telehealth data

There were differences in the level of understanding about the spatial skills for different age and gender groups. Females and those in the age group above 30 years had either no or minimal spatial skills (Fig 3 and 4). Participants in both the age groups preferred spatiotemporal data

dimension. Similarly more than half of the female (53%; n=7) and male participants (72%; n=5) preferred spatiotemporal data dimension of the telehealth data.

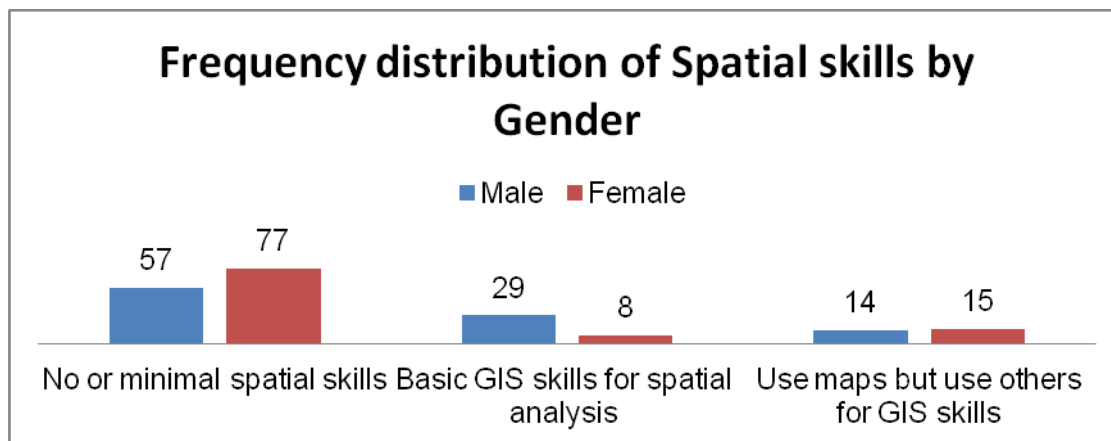


Figure 3. Frequency distribution of spatial skills by gender among the study participants

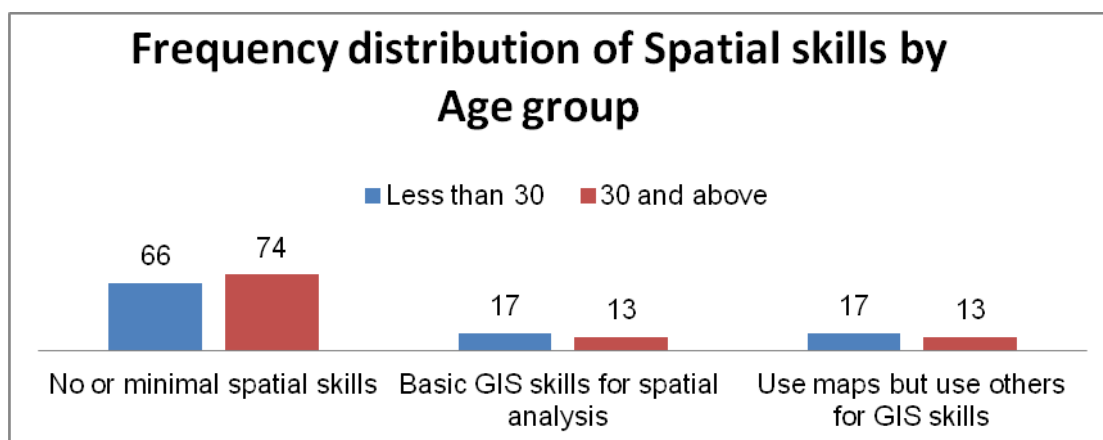


Figure 4. Frequency distribution of spatial skills by age group among study participants

Results showed that participants with no or basic role in data analysis had less preference to analyze the spatial dimension of the data while the participants with moderate to large data exploratory role had greater preference for analyzing the data's both spatial and temporal dimensions (Figure 5).

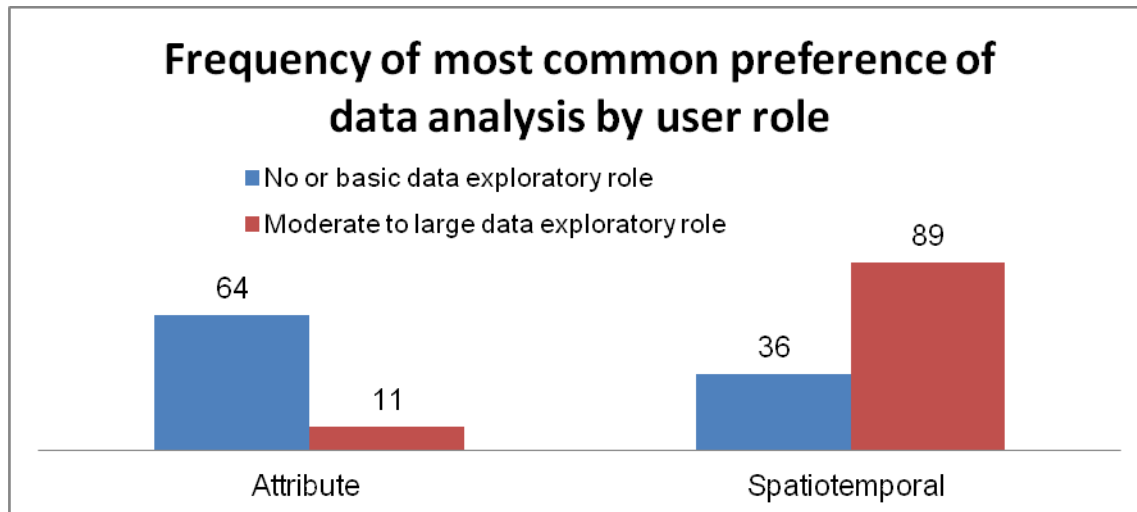


Figure 5. Frequency (%) distribution of data dimension (attribute versus spatiotemporal) by data exploratory role (no or basic versus moderate or large data exploratory role)

Results also showed that of the 45% participants with no GeoVis familiarity 33% had moderate to large data exploratory role, 89% had no spatial skills while 44% preferred analyzing both spatial and temporal dimensions of the data. This indicates that the users involved with the telehealth program, despite being having a moderate to large exploratory role in the data analysis and understanding the significance of both spatial and temporal dimensions of the data were not able to fully explore the data because of their lack of familiarity with the GeoVis and limited spatial skills.

These results indicate that users have different roles and skills, have different information needs, and have different preferences on how to represent the telehealth data for meaningful purpose. The results demonstrate a need to develop a human centered GeoVis system that addresses the users' needs and is easy to learn and use.

Qualitative data results

Results of open-ended interviews showed that participants had limited experience to view data on maps but had great experience in using tables and graphics. Hundred percent of the participants agreed that visualizing telehealth data on maps would be extremely relevant. Participants also indicated that this will allow them to view multiple indicators or different views of the same data and allow them to compare the participation rates of the various health unit centers and municipalities in the telehealth sessions. One of the participant also suggested that

viewing data on maps would facilitate to *“study the level of problems in telehealth and assess where the demand is coming from and where it is needed to improve the delivery of telehealth”*.

Almost all the participants had some exploratory role with the analysis of telehealth related data; however the types of data that they were analyzing were different based on their roles and responsibilities. Majority of the participants wanted to report the results of the data analysis as means, frequency (%) and median for the various variables of interest. For e.g. to assess participation of the health unit centers and municipalities in the telehealth related sessions (n=7), type of professionals participating in these sessions (n=5) and frequency of technical difficulties during the conduct of telehealth sessions (n=5). The participants also felt that it would be easy to identify whether a health center is active or no through its participation in the sessions. It was also indicated by the participants to perform analysis that would either rank or compare the municipality and health unit center based on their participation in the telehealth sessions. Another important task felt by the users was to assess best time (morning versus afternoon) of participation for the telehealth users. The participants also expressed interest to assess the frequency of most common professional categories (e.g. doctors, nurses or community health workers) that were participating in the telehealth sessions. This information was perceived extremely important by the study participants as it will enable them to have a timely intervention.

Majority of the participants (n=8) agreed to have maps as the first choice to represent the data as it will be able to display the events both in place and time. One of the participants stated that *“it is a dream since the start of the telehealth program to use the GeoVis application to evaluate the participation of health centers in telehealth services. In my opinion images speak more than words”*. Participants suggested that dynamic maps would be much better than static maps as it will facilitate to detect trends. Other modalities of data representation included tables and graphs (n=7). Majority of the participants wanted to review the results on a monthly basis (n=6). However participants with an administrative role wanted to review the results on a daily to weekly basis (n=4).

Participants had limited experience of using GeoVis application and those with experience had some familiarity with Google maps or Google Earth. Currently all the participants were using Microsoft excel to analyze the telehealth data. Majority of the participants (n=8) agreed that viewing telehealth data on maps would be extremely relevant. The tasks that the participants would most want to perform included comparing and ranking the health unit centers and municipalities participation in the telehealth sessions.

Results showed that the greatest benefits of the GeoVis application will be to the government, telehealth team, municipality administrators and the telehealth managers of the telehealth centers. One of the participant believed that *“it will allow the government to make better resource allocation of the investments for the following year”*. Another participant perceived that *“GeoVis enabled evaluation will facilitate them to understand better the needs of the municipalities and the health centers by analyzing the various telehealth service indicators such as kind of specialty that is in demand, kind of referral that is given and the kind of specialty missing in that municipality”*. Further it will also allow the government to see how the telehealth services are utilized, what areas generate more demand and referrals so that resources are appropriately planned. Overall, majority of the participants despite having limited GeoVis skills were strongly motivated and found it extremely relevant to utilize GeoVis to evaluate telehealth program. The results of both the qualitative and quantitative data describe the overall utility of GeoVis application to facilitate visual exploration of telehealth a kind of public health data for timely interventions.

Discussion

The GeoVis framework proposed integrates the principles of public health, human centered approach and cognitive fit theory to help us design systems that will have the right knowledge and information structure to match those of the users. Enabling the efficient usage of GeoVis representations as interfaces to data remains a crucial challenge to developing GeoVis applications. It is not enough to provide a visual method alone rather we must develop GeoVis applications that are accessible to users whose expertise exists outside the realm of GIScience. The current study presents a proof of concept to explore the utility of GeoVis to evaluate a telehealth program in Brazil. To our knowledge, this is the first study to assess the perception of the users to possibly utilize GeoVis as a method to evaluate telehealth program. A mixed methods approach used in the study facilitates both quantitative and qualitative feedback for better understanding of the users and their opinions and preferences towards using GeoVis application in context to telehealth data.

The study participants had varying level of expertise, prior familiarity with spatial skills and knowledge of GeoVis. The findings of our study describe the users involved, their diverse roles, and types of data that the users are involved with and the different analysis needs of each one of them. Better GeoVis applications can be created through a good knowledge of cognitive processes (Slocum et al., 2001) as it will result in applications that are both easy to learn and

will also have increase user acceptance. The early involvement of potential users is a core principle of HC approach with the purpose of developing applications that are useful and appropriate for the target domain (Bhowmick et al., 2008).

Results of our study also show some age and gender differences in the participants' expertise of using GeoVis applications. There were differences in the level of understanding about the spatial skills for different age and gender groups. Females and those in the age group above 30 years had either no or minimal spatial skills (Fig 3 and 4). Participants in both the age groups preferred spatiotemporal data dimension. Similarly more than half of the female (53%; n=7) and male participants (72%; n=5) preferred spatiotemporal data dimension of the telehealth data. These results illustrate age and gender variations for exploring the telehealth data among the diverse users. Prior studies have also shown similar results where it was found that males and females perform differently at dynamic spatial reasoning tasks and so is an important variable to take into account when designing GeoVis applications (Contreras, Rubio, Peña, & Santacreu, 2007). Similarly results of previous study have shown that there is a decline in the spatial visualization abilities in middle and late adulthood and so their implications for GeoVis need to be investigated (Salthouse, 2009).

The users had had varied roles and responsibilities and came back from diverse backgrounds including medical, nursing, computer sciences, biomedical informatics, statistics, dentistry, administration and engineering. The understanding about the user needs is essential to ensure that the technology is appropriately functional and will be useful to complete tasks (Bowen & Reeves, 2007).

Results of our study show that despite having no or minimal spatial skills, there was a strong motivation and relevance among the telehealth users to utilize GeoVis. The users also expressed limitation in how they are currently analyzing the data and their inability to analyze the data to its full potential such that useful information can be generated in a timely manner for appropriate interventions. Instead the users wait for too long for the results to be analyzed before any decision can be made regarding the active and inactive health unit centers and municipalities.

Results of our open-ended interviews described the type of data analysis performed, preferences on how to represent the results including maps, graphics and tables, level of granularity of the data analysis, ability to view, compare and rank the different indicator variables against municipalities and the health centers at different time intervals. The

participants also perceived strongly that GeoVis application would be greatly beneficial to the diverse group of stakeholders including the NUTES telehealth team, participating health centers, managers of the municipalities and the government. The feedback gathered during this pilot study will help us to develop Human centered GeoVis application the “SanaViz” an interactive Web-enabled system to evaluate telehealth programs. Overall the study findings demonstrate a growing need for the use of GeoVis applications to evaluate telehealth data.

References

- Adams, M. E., McCall, N. T., Gray, D. T., Orza, M. J., & Chalmers, T. C. (1992). Economic analysis in randomized control trials. *Medical Care*, 30, 231-243.
- Aigner, W., Miksch, S., Mueller, W., Schumann, H., & Tominski, C. (2007). Visualizing time - oriented data: A systematic review. *Computers and Graphics*, 31, 401-409.
- Bhowmick, T., Griffin, A. L., MacEachren, A. M., Kluhsman, B. C., & Lengerich, E. J. (2008). Informing geospatial toolset design: Understanding the process of cancer data exploration and analysis. *Health & Place*, 14(3), 576-607.
- Bhowmick, T., Robinson, A. C., Gruver, A., MacEachren, A. M., & Lengerich, E. J. (2008). Distributed usability evaluation of the Pennsylvania Cancer Atlas. *International Journal of Health Geographics*, 7(1), 36.
- Bowen, J., & Reeves, S. (2007). Formal models for informal GUI designs. *Electronic Notes in Theoretical Computer Science*, 183, 57-72.
- Brandling-Bennett, H. A., Kedar, I., Pallin, D. J., Jacques, G., Gumley, G. J., & Kvedar, J. C. (2005). Delivering health care in rural Cambodia via store-and-forward telemedicine: A pilot study. *Telemedicine Journal & e-Health*, 11(1), 56-62.
- Braveman, P., & Tarimo, E. (2002). Social inequalities in health within countries: Not only an issue for affluent nations. *Social Science & Medicine*, 54(11), 1621-1635.
- Castillo-Riquelme, M., Chalabi, Z., Lord, J., Guhl, F., Campbell-Lendrum, D., Davies, C., & Fox-Rushby, J. (2008). Modelling geographic variation in the cost-effectiveness of control policies for infectious vector diseases: The example of Chagas disease. *Journal of Health Economics*, 27(2), 405-426.
- Chen, Y., Yi, Q., & Mao, Y. (2008). Cluster of liver cancer and immigration: A geographic analysis of incidence data for Ontario 1998–2002. *International Journal of Health Geographics*, 7(1), 28.

- Cinnamon, J., Rinner, C., Cusimano, M. D., Marshall, S., Bekele, T., Hernandez, T Chipman, M. L. (2009). Evaluating web-based static, animated and interactive maps for injury prevention. *Geospatial Health*, 4(1), 3-16.
- Contreras, M. J., Rubio, V. J., Peña, D., Colom, R., & Santacreu, J. (2007). Sex differences in dynamic spatial ability: The unsolved question of performance factors. *Memory & Cognition*, 35(2), 297-303.
- Crampton, J. W. (2002). Interactivity types in geographic visualization. *Cartography and Geographic Information Science*, 29(2), 85-98.
- Dasgupta, A., & Deb, S. (2008). Telemedicine: A new horizon in public health in India. *Indian Journal of Community Medicine: Official Publication of Indian Association of Preventive & Social Medicine*, 33(1), 3.
- Dennis, A. R., & Carte, T. A. (1998). Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations. *Information Systems Research*, 9(2), 194-203.
- Dix, A., Finlay, J., Abowd, G., & Beale, R. (1998): *Human computer interaction*. Prentice Hall, Englewood Cliffs, NJ, USA.
- Edsall, R. M., & Sidney, L. R. (2005). Applications of a cognitively informed framework for the design of interactive spatio-temporal representations. *Exploring Geovisualization*, 577-590.
- Evans, B. J. (1997). Dynamic display of spatial data-reliability: Does it benefit the map user? *Computers & Geosciences*, 23(4), 409-422.
- Fleishman, E. A., Quaintance, M. K., & Broedling, L. A. (1984). *Taxonomies of human performance: The description of human tasks*. Academic Press, Orlando, FL.
- Fuhrmann, S., Ahonen-Rainio, P., Edsall, R. M., Fabrikant, S. I., Koua, E. L., Tobón, C., . . . Wilson, S. (2005). Making useful and useable geovisualization: Design and evaluation issues. *Exploring Geovisualization*, (November 2004), 551-566.
- Gahegan, M., Wachowicz, M., Harrower, M., & Rhyne, T. M. (2001). The integration of geographic visualization with knowledge discovery in databases and geocomputation. *Cartography and Geographic Information Science*, 28(1), 29-44.
- Gebreab, S. Y., Gillies, R. R., Munger, R. G., & Symanzik, J. (2008). Visualization and interpretation of birth defects data using linked micromap plots. *Birth Defects Research Part A: Clinical and Molecular Teratology*, 82(2), 110-119.
- Haggett, P. (1990). *The geographer's art*. B. Blackwell, Oxford, UK.

- Horner, M. W., & Downs, J. A. (2008). Analysis of effects of socioeconomic status on hurricane disaster relief plans. *Transportation Research Record: Journal of the Transportation Research Board*, 2067(1), 1-10.
- ISO. (1999). 13407: Human-centred design processes for interactive systems. Geneva: ISO.
- Jamison, D. T. (2006). Disease control priorities in developing countries. Washington, DC: Oxford University Press.
- Joshi, A., Novaes, M.A., Iyengar, S., Machiavelli, J.L., Zhang, J., Vogler, R., & Hsu, E. (2011). Evaluating participant satisfaction perspective towards tele-education services in Brazil: *Journal of Telemedicine and Telecare*, 17(7), 341-345.
- Kawasaki, S., Ito, S., Satoh, S., Mori, Y., Saito, T., Fukushima, H., .Sekihara, H. (2003). Use of telemedicine in periodic screening of diabetic retinopathy. *Telemedicine Journal and E-Health*, 9(3), 235-239.
- Kushniruk, A. W., Patel, V. L., & Cimino, J. J. (1997). Usability testing in medical informatics: Cognitive approaches to evaluation of information systems and user interfaces. *Proceedings from the AMIA Annual Fall Symposium*, 218.
- Lattimore Jr, M. R. (1999). A store-forward ophthalmic telemedicine case report from deployed US army forces in Kuwait. *Telemedicine Journal*, 5(3), 309-313.
- Lauesen, S. (2005). *User interface design: A software engineering perspective*. Addison-Wesley. Reading, MA.
- Lee, C., & Irving, J. L. (1999). Sources of spatial data for community health planning. *Journal of Public Health Management and Practice*, 5(4), 7.
- Liou, T. H., Chen, C. H., Hsu, C. Y., Chou, P., & Chiu, H. W. (2006). A pilot study of videoconferencing for an internet-based weight loss programme for obese adults in Taiwan. *Journal of Telemedicine and Telecare*, 12(7), 370-373.
- Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, 20 (7), 703-726.
- McGuinness, C. (1994). Expert/novice use of visualization tools. *Visualization in Modern Cartography*, 185-199.
- Muntz, R., Barclay, T., Dozier, J., Faloutsos, C., Maceachren, A., Martin, J., Satyanarayanan, M. (2003). IT roadmap to a geospatial future, report of the committee on intersections between geospatial information and information technology. Washington, DC: National Academy of Sciences.

- Nielsen, J., & Landauer, T. K. (1993). A mathematical model of the finding of usability problems. *Proceedings from the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems*, 206-213. Amsterdam, Netherlands: ACM.
- Parmanto, B., Paramita, M. V., Sugiantara, W., Pramana, G., Scotch, M., & Burke, D. S. (2008). Spatial and multidimensional visualization of Indonesia's village health statistics. *International Journal of Health Geographics*, 7(1), 30.
- Richards, T. B., Croner, C. M., Rushton, G., Brown, C. K., & Fowler, L. (1999). Geographic information systems and public health: Mapping the future. *Public Health Reports-US*, 114, 359-373.
- Rivest, S., Bedard, Y., & Marchand, P. (2001). Toward better support for spatial decision making: Defining the characteristics of spatial on-line analytical processing (SOLAP). *Geomatica*, 55(4), 539-555.
- Robert, C., & Ellen, C. (2009). Choropleth map legend design for visualizing community health disparities. *International Journal of Health Geographics*, 8, 52.
- Robinson, A. C. (2005). Geovisualization and epidemiology: A general design framework. *Proceedings from the 22nd International Cartographic Conference. A Coruña, Spain*.
- Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., & MacEachren, A. M. (2005). Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science*, 32(4), 243.
- Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging*, 30(4), 507-514.
- Schuurman, N., Cinnamon, J., Crooks, V., & Hameed, S. M. (2009). Pedestrian injury and the built environment: An environmental scan of hotspots. *BMC Public Health*, 9(1), 233.
- Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S., & Hedley, N. R. (2001). Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, 28(1), 61-75.
- Sopan, A., Noh, A., Lee, G., Rosenfeld, P., Karol, S., & Shneiderman, B. (2012). Community health map: A geospatial and multivariate data visualization tool for public health datasets. *Government Information Quarterly*.
- Timpka, T., Ölvander, C., & Hallberg, N. (2008). Information system needs in health promotion: A case study of the safe community programme using requirements engineering methods. *Health Informatics Journal*, 14(3), 183-193.

- Valiati, E. R. A., Freitas, C. M. D. S., & Pimenta, M. S. (2008). Using multi-dimensional in-depth long-term case studies for information visualization evaluation. *Proceedings of the 2008 Conference on Beyond Time and Errors: Novel evaluation Methods for Information Visualization*, 9.
- van der Wilk, E. A., & Verschuuren, M. (2010). Adding value to figures: A web-based European public health information system. *Journal of Telemedicine and Telecare*, 16(1), 35-41.
- van Elzakker, C. P. J. M. (2003). The use of maps in exploration of geographic data. Proceedings from the 21st International Cartographic Conference (ICC). Durban, South Africa.
- Walton, J. (1996). Data mining and visualization. *Database programming & design*, 9, 5.
- Wang, X. Y., Hu, W., & Tong, S. (2009). Long-term exposure to gaseous air pollutants and cardio-respiratory mortality in Brisbane, Australia. *Geospatial Health*, 3(2), 257-263.
- Wehrend, S., & Lewis, C. (1990). A problem-oriented classification of visualization techniques. *Proceedings from the 1st Conference on Visualization'90*, 139-143.
- Yip, M. P., Mackenzie, A., & Chan, J. (2002). Patient satisfaction with telediabetes education in Hong Kong. *Journal of Telemedicine and Telecare*, 8(1), 48-51.

Designing Human Centered GeoVisualization application - the SanaViz - for telehealth users: A case study

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Abstract

Background: Public health data is typically organized by geospatial unit. GeoVisualization (GeoVis) allows users to see information visually on a map.

Objectives: Examine telehealth users' perceptions towards existing public health GeoVis applications and obtains users' feedback about features important for the design and development of Human Centered GeoVis application "the SanaViz".

Methods: We employed a cross sectional study design using mixed methods approach for this pilot study. Twenty users involved with the NUTES telehealth center at Federal University of Pernambuco (UFPE), Recife, Brazil were enrolled. Open and closed ended questionnaires were used to gather data. We performed audio recording for the interviews. Information gathered included socio-demographics, prior spatial skills and perception towards use of GeoVis to evaluate telehealth services. Card sorting and sketching methods were employed. Univariate analysis was performed for the continuous and categorical variables. Qualitative analysis was performed for open ended questions.

Results: Existing Public Health GeoVis applications were difficult to use. Results found interaction features zooming, linking and brushing and representation features Google maps, tables and bar chart as most preferred GeoVis features.

Conclusions: Early involvement of users is essential to identify features necessary to be part of the human centered GeoVis application "the SanaViz".

Background

Public health data is typically organized at a geospatial unit. Spatial component includes data with location attributes and can provide insight into how and where to obtain important services (Jamison, 2006; Richards, Croner, Rushton, Brown, & Fowler, 1999; Rivest, Bedard, & Marchand, 2001) while temporal component records time of the observation and enables users to learn from the past to predict, plan, and build the future (Aigner, Miksch, Mueller, Schumann, & Tominski, 2007). Geospatial data exploration and visual analysis can be used to inform public-health research, planning and decision making. Public health organizations are increasingly harnessing geospatial technologies to aid in decision support for a broad range of purpose, including disease surveillance, health service allocation and for targeting health promotion initiatives. As public health datasets become increasingly complex, there is a growing need for methods and applications to support the construction of knowledge (Bhowmick, Griffin, MacEachren, Kluhsman, & Lengerich, 2008).

Geovisualization (GeoVis) developed as a field of research in the early 1980s is based largely on the work of French graphic theorist Jacques Bertin (Cinnamon et al., 2009). It begins with data exploration, continues to analysis, transitions into synthesis of results and finishes with presentation of findings (Cinnamon et al., 2009). Dynamic, multi-representational GeoVis applications enable geographers to explore and analyze multivariate spatial data. Visualization of such data necessarily involves maps. New representation and interaction features to visualize geospatial data requires an understanding of the visual tools used for data exploration and knowledge construction.

There is a need to assess the usefulness and usability of GeoVis applications as new types of interactions emerge (Muntz et al., 2003). Usability is defined as “the effectiveness, efficiency and satisfaction with which specific users achieve specified goals in particular environments”

(ISO, 1999). Making systems more usable have noticeable benefits for users by ensuring easy to use systems, which are less stressful for the user and therefore more acceptable. A user-centered design can provide financial benefits for the system developer in reduced production costs, reduced support costs, reduced costs in use, and improved product quality (Earthy, 1999). Such assessments focus on the effectiveness, usefulness and performance of an application. This is needed in GeoVis because use and usability testing can provide insight into how a visual interface can support data-exploration tasks (Andrienko et al., 2002). Usability testing includes evaluation of information systems with participants who are representative of the target user population as they interact with an information technology. The design of functionality is a key step in both usefulness and effectiveness of GeoVis (Andrienko et al., 2002).

Requirement analysis forms a basis towards development of the GeoVis prototype and tells what kind of functionality the prototype should have or what the prototype should be able to do. Despite the obvious benefits of maps that are easy to use and understand, limited guidance exists addressing how to actually design simple and functional geographic visualization applications for use in the public health realm (Robinson, Chen, Lengerich, Meyer, & MacEachren, 2005).

Several prior GeoVis applications that were commonly utilized in public health were reviewed. Those GeoVis applications that included spatiotemporal components of public health data to represent information were employed in context to public health relevance were included. Some of these public health GeoVis applications have been outlined below.

(I) Pennsylvania Cancer Atlas (PA-CA) (Bhowmick, Robinson, Gruver, MacEachren, & Lengerich, 2008): PA-CA Atlas, an interactive online atlas, to help policy-makers, program managers, and epidemiologists with tasks related to cancer prevention and control. (Figure 1). Prior studies have shown that features of PA-CA were not

explanatory, difficult to use by non-experts and users were not able to change default map aggregation units (Bhowmick, Robinson, et al., 2008).

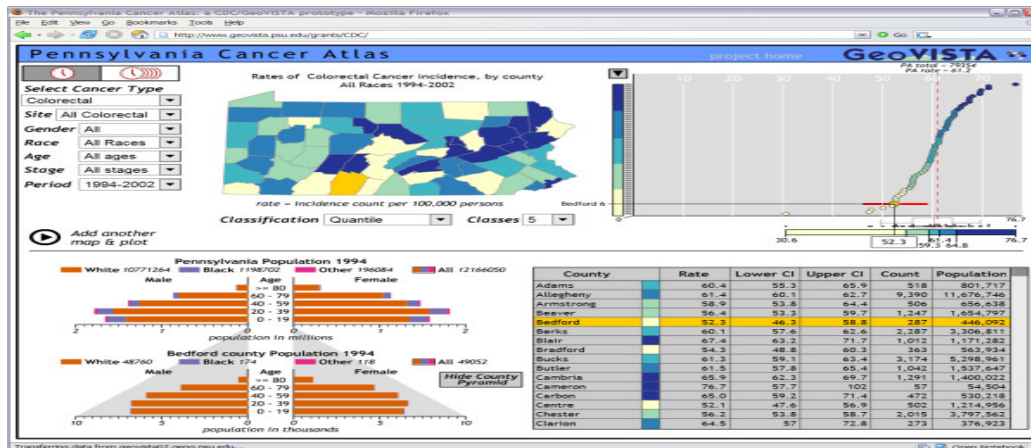


Figure 1. PA-CA GeoVis

(II) **Exploratory Spatiotemporal Analysis Toolkit (ESTAT)** (Robinson, 2005): It is designed to provide cancer researchers with visual tools to explore multivariate spatiotemporal data. Results showed lack of a number of the essential ingredients needed to make ESTAT practical for use by typical public-health researchers (Figure 2). Users never got very far into actual epidemiological analysis because of the clumsiness of the interface (Robinson, 2005). Users lacked familiarity with the visualization methods being applied and visualizations were not widely understood with the users in mind.

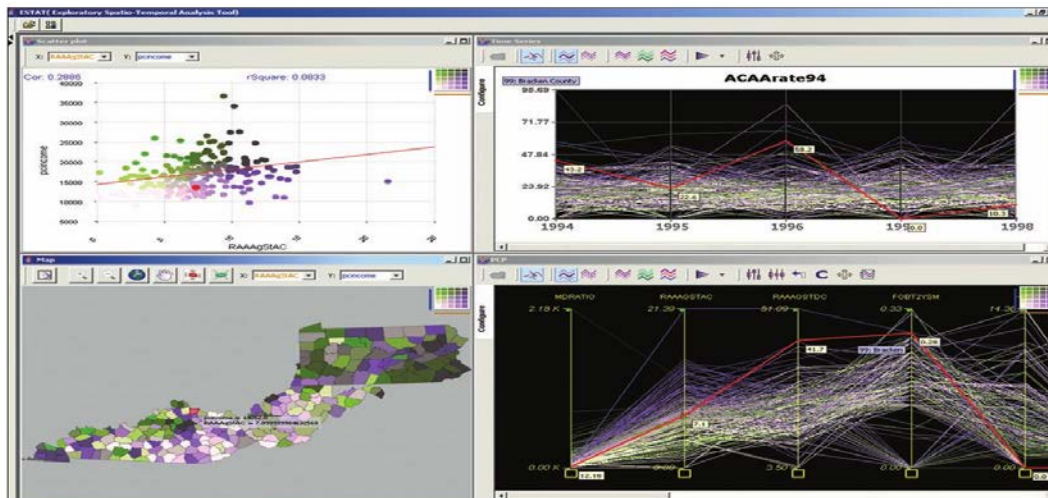


Figure 2. The ESTAT GeoVis

(III) Community Health Map (CHM) (Sopan et al., 2012): A Web application that enables users to visualize health care data in multivariate space as well as geospatially. It is designed to aid exploration and deliver deep insights for policy makers, consumer groups and academic researchers (Figure 3). Prior study has shown lack of user and task involvement early in the process of design of the application (Sopan et al., 2012).

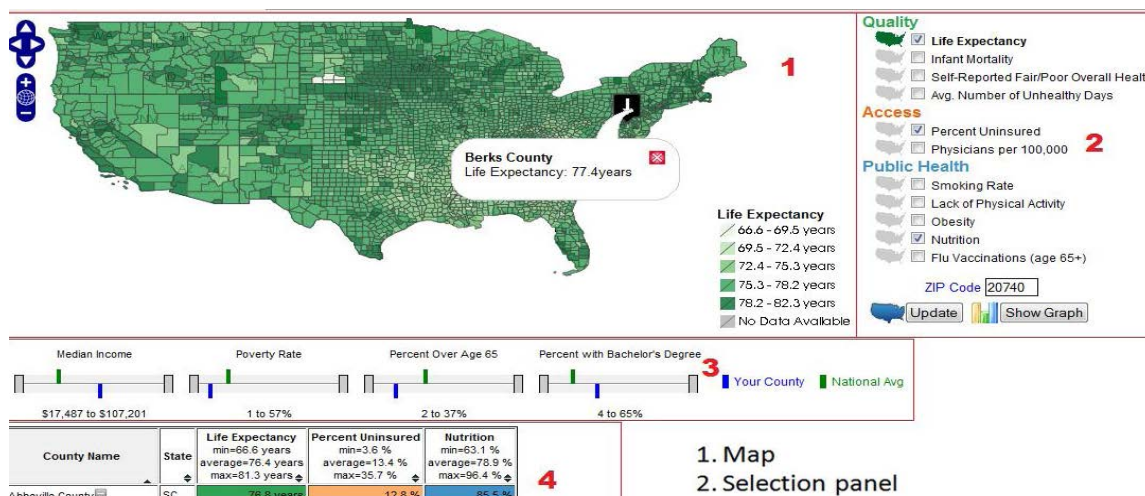


Figure 3. Community Health Map (CHM)

(IV) Instant Atlas (van der Wilk & Verschuuren, 2010): Instant Atlas™ enables information analysts and researchers to create highly interactive dynamic and profile reports that combine statistics and map data to improve data visualization, enhance communication, and engage people in more informed decision making (Figure 4).

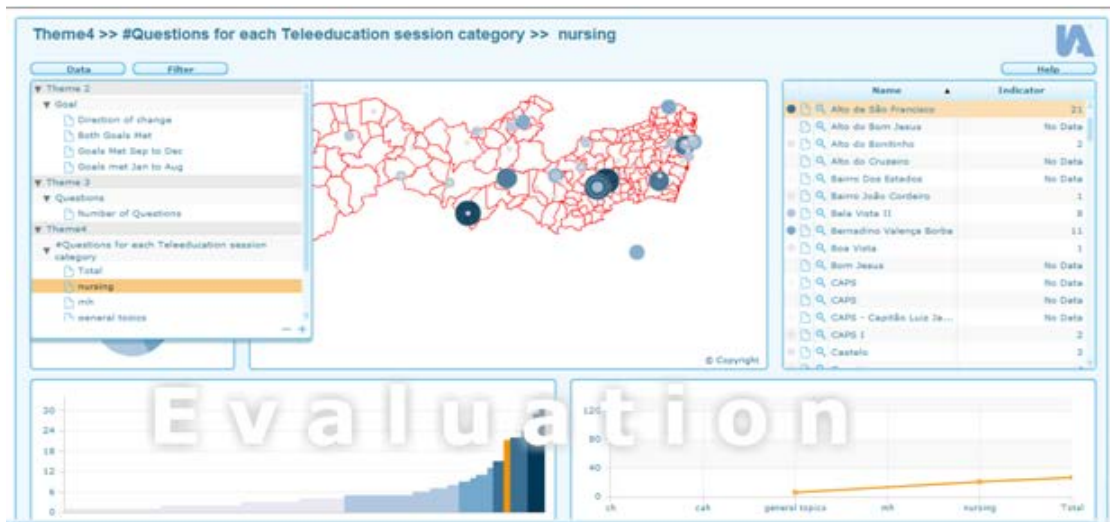


Figure 4. Instant Atlas

A majority of the existing GeoVis applications is designed according to the technology and software engineering principles. Existing public health GeoVis applications often overlook user-characteristics, tasks, preferences and usability concerns resulting in systems that generate more confusion than benefits, or simply remain inadequate (Johnson, Johnson, & Zhang, 2005; Timpka, Ölvander, & Hallberg, 2008). Domain specific considerations have been overlooked and end user input has been incorporated only after key functionality and interface design issues have been decided. GeoVis applications are difficult to learn and use, are predominantly generic and do not address specific users (Bowen & Reeves, 2007; Robinson et al., 2005). Recently, there has been a shift towards user-centered design (Fuhrmann et al., 2005). Better GeoVis applications can be created through a usability approach and with knowledge of cognitive processes (Slocum et al., 2001).

The objectives of the present study are to examine telehealth users' perceptions towards existing public health GeoVis applications and to gather their feedback about the necessary components that might be important for the design and development of a useful and effective Human Centered GeoVis application the "SanaViz". To our knowledge this is the first study to utilize GeoVis as a method to evaluate Telehealth program.

Methods

A mixed method cross sectional study design was employed for this pilot study. A convenient sample of twenty participants involved with the telehealth program at the NUTES Telehealth Center at Federal University of Pernambuco, Recife, Brazil was enrolled during September-October 2011. Selection of the sample size ($n=20$) was based on recommendations from the usability engineering literature (Nielsen & Landauer, 1993). The majority of the usability issues can often be highlighted from a representative sample which typically involves as few as 8-10 participants (Kushniruk, Patel, & Cimino, 1997). The study was approved the University of Texas Health Science Center Institutional Review Board (IRB # HSC-GEN-11-0447).

Procedure

The study participants were given a brief 45 minutes presentation about the purpose of this pilot study. Participants were then shown existing GeoVis applications. An example scenario describing use of GeoVis to facilitate visual exploration of telehealth data was demonstrated. Participants were then asked to explore the existing GeoVis applications. Study participants were then asked to fill in both open ended and close-ended questionnaires.

Data gathering techniques

Data gathering approaches included questionnaires, interviews, card sorting and sketching. Interviews were done in both English and Portuguese and audio recording was performed. Transcription of the audio content into English was done by a certified translator.

a. Questionnaires

Socio-demographic questionnaire: Information gathered included age (years), gender, prior education, user categories and familiarity with the use of computer and prior use of GeoVis applications.

System Usability Scale (SUS): SUS method is a 10 item questionnaire that refers to appropriateness of the application functionality by assessing whether the needs and requirements of the users when carrying the tasks are met or not (Brooke, 1996). It also assesses the extent to which users view the GeoVis applications as supportive for their goals and tasks. The questions consist of close-ended questions answered on a five point scale of “Strongly agree” to “Strongly disagree”. Prior studies have shown that SUS yielded the most reliable results across sample sizes, and provides a good and valid method of comparing different interfaces’ usability (Bangor, Kortum, & Miller, 2008; Tullis & Stetson, 2004).

b. Card sorting: Card sorting was employed for establishing user insight into design ideas (Faiks & Hyland, 2000; Tohidi, Buxton, Baecker, & Sellen, 2006). After GeoVis presentation, participants were given 3x5 note cards labeled with individual interactions and representations (Arnowitz, Arent, & Berger, 2006). Participants accordingly categorized GeoVis features as very relevant/somewhat relevant/unsure/somewhat irrelevant/completely irrelevant (Lloyd, 2009). Before each run, we thoroughly shuffled the cards so that previous participant does not influence the current one.

c. Sketching: User sketching can be utilized for establishing user insight into design ideas (Faiks & Hyland, 2000; Tohidi et al., 2006). Enabling users to sketch their ideas can facilitate reflection and encourage deeper interpretation and analysis in human-centered design (Tohidi et al., 2006). The users were asked to sketch ideas for specific tasks. The number of elements

in each design corresponding to the GeoVis presentation was counted. A count was also made of elements not included in the GeoVis application (Lloyd, 2009).

d. Open ended interviews: Qualitative data was gathered using a set of structured open-ended questions to gather participant's experience of using GeoVis applications. These questions included;

- What features and/or operations within the GeoVis application:
 - Do you like it? Why?
 - Do you feel the need for improvement? Why?
 - Do you think who possibly would benefit from using GeoVis? Why?

Statistical Analysis

Univariate analysis was performed to report mean and standard deviation for continuous variables while frequency analysis was performed for the categorical variables as needed. Frequency analysis was also performed for the various GeoVis features that were found relevant or not relevant across the existing GeoVis applications. Quantitative information was derived by making a numerical count of the necessary features within each sketch that might be useful for the newly designed GeoVis application "the SanaViz". Features that appeared frequently from more than one participant indicate perceived utility to the task in hand. For the open-ended questions, we performed qualitative analysis using NVIVO software (Slocum et al., 2001). All other quantitative analysis was performed using SAS V9.1.

Results

(i) Study participants' characteristics

The average age of the participants was 28 years (SD=7), majority of them were females and 90% of them were graduate professionals. The participants' came from a range of diverse backgrounds including nursing, computer science, biomedical informatics, statistics, dentistry,

administration and engineering. 100% of them were somewhat to very familiar with the use of computers. Only 5% of them had familiarity with any kind of GeoVis applications. Those who were familiar were most familiar with the use of Google maps.

(ii) SUS- Evaluation of existing GeoVis applications

Instant Atlas (60%; n=12) and PA-CA (40%; n=8) were the preferred GeoVis applications that the study participants would like to use. ESTAT and CHM applications were comparatively less useful to the participants as compared to the others. ESTAT was found to be unnecessary complex and cumbersome to use. Majority of the participants did not find Instant Atlas GeoVis application complex; however; felt that they would need the support of a technical person to be able to use it (Table 1).

Questions	PA-CA	ESTAT	CHM	Instant Atlas
<i>I think that I would like to use this GeoVis application frequently</i>				
Strongly agree	8 (40%)		4 (20%)	12 (60%)
Agree	12 (60%)		11 (55%)	8 (40%)
Neutral		2 (10%)	4 (20%)	
Disagree		10 (50%)	1 (5%)	
Strongly disagree		8 (40%)		
<i>I found the GeoVis application unnecessarily complex</i>				
Strongly agree	1 (5%)	12 (60%)		1 (5%)
Agree	2 (10%)	7 (35%)	5 (25%)	
Neutral	2 (10%)	1 (5%)	3 (15%)	4 (20%)
Disagree	9 (45%)		7 (35%)	8 (40%)

Strongly disagree	6 (30%)		5 (25%)	7 (35%)
<i>I thought the GeoVis application was easy to use</i>				
Strongly agree	8 (40%)		7 (35%)	10 (50%)
Agree	9 (45%)	2 (10%)	10 (50%)	6 (30%)
Neutral			1 (5%)	3 (15%)
Disagree	3 (15%)	5 (25%)		1 (5%)
Strongly disagree		13 (65%)	2 (10%)	
<i>I think that I would need the support of a technical person to be able to use the GeoVis application</i>				
Strongly agree	1 (5%)	10 (50%)		6 (30%)
Agree	6 (30%)	7 (35%)	8 (40%)	1 (5%)
Neutral	2 (10%)	2 (10%)	3 (15%)	3 (15%)
Disagree	8 (40%)		6 (30%)	6 (30%)
Strongly disagree	3 (15%)	1 (5%)	3 (15%)	4 (20%)
<i>I think that I would need detailed help and tutorials to be able to use the GeoVis application.</i>				
Strongly agree	1 (5%)	12 (60%)		
Agree	10 (50%)	8 (40%)	8 (40%)	7 (35%)
Neutral			4 (20%)	6 (30%)
Disagree	7 (35%)		7 (35%)	7 (35%)
Strongly disagree	2 (10%)		1 (5%)	
<i>I found the various functions in this GeoVis application were well integrated.</i>				
Strongly agree	8 (40%)	1 (5%)	4 (20%)	8 (40%)

Agree	11 (55%)	2 (10%)	9 (45%)	11 (55%)
Neutral		7 (35%)	5 (25%)	
Disagree	1 (5%)	8 (40%)	1 (5%)	1 (5%)
Strongly disagree		2 (10%)	1 (5%)	
<i>I thought there was too much inconsistency in this GeoVis application.</i>				
Strongly agree	3 (15%)		3 (15%)	1 (5%)
Agree	6 (30%)	3 (5%)	4 (20%)	8 (40%)
Neutral	7 (35%)	14 (70%)	7 (35%)	7 (35%)
Disagree	3 (15%)	1 (5%)	4 (20%)	2 (10%)
Strongly disagree	1 (5%)	2 (10%)	2 (10%)	2 (10%)
<i>I think that most people would learn to use this GeoVis application very quickly.</i>				
Strongly agree	6 (30%)		4 (20%)	9 (45%)
Agree	7 (35%)		8 (40%)	6 (30%)
Neutral	1 (5%)	2 (10%)	2 (10%)	3 (15%)
Disagree	5 (25%)	6 (30%)	5 (25%)	2 (10%)
Strongly disagree	1 (5%)	12 (60%)	1 (5%)	
<i>I found the GeoVis application very cumbersome to use</i>				
Strongly agree	1 (5%)	8 (40%)	1 (5%)	1 (5%)
Agree	3 (15%)	9 (45%)		1 (5%)
Neutral	3 (15%)	2 (5%)	5 (25%)	2 (10%)
Disagree	10 (50%)		11 (55%)	11 (55%)
Strongly disagree	3 (15%)	1 (5%)	3 (15%)	5 (25%)

<i>I felt very confident using the GeoVis application.</i>				
Strongly agree	6 (30%)	1 (5%)	5 (20%)	9 (45%)
Agree	9 (45%)	1 (5%)	8 (40%)	8 (40%)
Neutral	4 (20%)	7 (35%)	5 (25%)	2 (10%)
Disagree	1 (5%)	7 (35%)	1 (5%)	1 (5%)
Strongly disagree		4 (20%)	1 (5%)	
<i>I needed to learn a lot of things before I could get going with this GeoVis application.</i>				
Strongly agree	1 (5%)	10 (50%)	1 (5%)	1 (5%)
Agree	3 (15%)	4 (20%)	4 (20%)	5 (25%)
Neutral	5 (25%)	3 (15%)	3 (15%)	4 (20%)
Disagree	7 (35%)	3 (15%)	9 (45%)	8 (40%)
Strongly disagree	4 (20%)		3 (15%)	2 (10%)

Table 1. Results of the SUS method for the various existing GeoVis applications

(iii) Card sorting results

Results of card sorting found zooming (75%; n=15), linking (70%; n=14) and brushing (65%; n=13) as very relevant interaction features and should be part of the GeoVis applications. Highlighting (60%; n=12), aggregation (60%; n=12), multiple views (55%; n=11) and filtering (N=50%; N=10) were also very relevant GeoVis interaction features. Tables (95%; n=19), bar chart (80%; n=16), choropleth maps (75%; n=15), linked views (75%; n=15) and bubble plot (70%; n=14) were preferred methods of representation of the data. Bivariate map (65%; n=13) and dynamic query filter (65%; n=13) were also identified as somewhat to very relevant features of any GeoVis application. Majority of the telehealth users found Parallel Coordinate Plot (PCP) irrelevant (65%; n=13) (Table 2).

Features	Response Options				
	Very relevant	Somewhat relevant	Unsure	Somewhat irrelevant	Completely irrelevant
Interactions					
Brushing	13 (65%)	5 (25%)		1 (5%)	1 (5%)
Linking	14 (70%)	5 (25%)		1 (5%)	
Zooming	15 (75%)	5 (25%)			
Temporal Animation	4 (20%)	9 (45%)	2 (10%)	4 (20%)	1 (5%)
Sorting	9 (45%)	9 (45%)	1 (5%)		1 (5%)
Remapping symbols	6 (30%)	7 (35%)	1 (5%)	6 (30%)	
Filtering	10 (50%)	9 (45%)		1 (5%)	
Multiple views	11 (55%)	9 (45%)			
Aggregation	12 (60%)	6 (30%)	1 (5%)	1 (5%)	
Highlighting	12 (60%)	7 (35%)		1 (5%)	
Dynamic classification	6 (30%)	8 (40%)	2 (10%)	4 (20%)	
Toggling	4 (20%)	11 (55%)	2 (10%)	3 (15%)	
Population pyramid	4 (20%)	8 (40%)	2 (10%)	4 (20%)	2 (10%)
Box Plot	8 (40%)	3 (15%)	5 (25%)	2 (10%)	1 (5%)
Parallel Coordinate Plot		5 (25%)	2 (10%)	5 (25%)	8 (40%)
Scatter plot	9 (45%)	4 (20%)	3 (15%)	2 (10%)	1 (5%)
Small multiples/linked views	7 (35%)	8 (40%)	2 (10%)	3 (15%)	
Bubble plot	7 (35%)	7 (35%)	1 (5%)	3 (15%)	1 (5%)

Time series plot	5 (25%)	7 (35%)	1 (5%)	6 (30%)	1 (5%)
Bivariate map	6 (30%)	7 (35%)	3 (15%)	4 (20%)	
Bar chart	9 (45%)	7 (35%)	2 (10%)	1 (5%)	
Dynamic query filter	6 (30%)	7 (35%)	4 (20%)	3 (15%)	
Choropleth Map	8 (40%)	7 (35%)	1 (5%)	3 (15%)	1 (5%)
Dot map	3 (15%)	7 (35%)	4 (20%)	5 (25%)	1 (5%)
Table	10 (50%)	9 (45%)		1 (5%)	

Table 2. Card sorting results

(ii) Stratified analysis by user roles, gender and prior spatial skills

Card sorting analysis stratified by user categories, gender, and prior spatial skills and GeoVis familiarity was performed.

(a) By user categories

The telehealth users were categorized as Administrator (A), Computer System Analyst (CSA), Health Informatics Researcher (HIR), Health Professional (HP), Project Manager (PM), Statisticians (S) and other (telehealth training personnel). Those interactions and representation features that were considered very relevant by the diverse user categories were reported. Results showed some differences in the way the different users perceived the relevance of the GeoVis features. Those in the administrator role perceived interactions features such as comparison, sorting, multiple views and aggregation very relevant. Temporal animation was found relevant among those who had statistical background while toggling was not found relevant by anyone (Table 3).

Interactions	User categories						
	A	CSA	HIR	HP	PM	S	Other
Zooming		Y	Y	Y	Y	Y	Y
Comparison	Y	Y	Y	Y		Y	Y
Brushing		Y	Y	Y	Y	Y	Y
Linking		Y	Y	Y	Y	Y	Y
Temporal Animation						Y	Y
Sorting	Y	Y			Y	Y	Y
Remapping symbols			Y			Y	Y
Suppression			Y	Y	Y		
Multiple views	Y	Y	Y	Y	Y	Y	
Extraction		Y	Y		Y	Y	Y
Aggregation	Y		Y	Y	Y		Y
Dynamic classification			Y		Y	Y	
Toggling							
Small Multiple linked views			Y	Y			Y
Representations							
Bar Chart	Y	Y	Y		Y	Y	
Scatter Plot			Y		Y	Y	Y
Box Plot			Y			Y	Y
Bubble Plot			Y		Y	Y	Y
Parallel coordinate							

plot							
Time series plot			Y			Y	
Choropleth Map	Y	Y	Y	Y			Y
Dot Map			Y				
Bivariate Map			Y		Y		Y
Population pyramid						Y	
Charts	Y	Y	Y	Y		Y	
Dynamic query filter		Y				Y	Y
Tables	Y	Y	Y	Y		Y	

Table 3. Card sorting analysis stratified by user categories. Here “Y” represents interaction and representation features considered very relevant.

Similar results were found with stratified analysis where majority of the user categories agreed having zooming, comparison, brushing, linking and multiple views as relevant features of the proposed Human centered GeoVis system the” SanaViz”. Toggling and parallel coordinate plot was not found to be relevant by any of the user categories (Table 4).

User categories	Interaction and Representation features
7	No interaction or representation feature was found where all agreed
6	Zooming, Comparison, Brushing, Linking, Multiple views
5	Sorting, Extraction, Aggregation, Bar chart, Choropleth map
4	Scatter plot and time series plot
3	Remapping symbols, suppression/filtering, dynamic classification, box plot, bivariate map and dynamic query filter
2	Temporal animation and time series plot
1	Dot map and Population pyramid
None of them	Toggling and parallel coordinate plot

Table 4. Interaction and representation features found relevant by 7 diverse user categories.

(b) By Gender

Gender differences were seen for the features such as temporal animation, dynamic classification, and small multiple/linked views, parallel coordinate, plot time series, plot and population pyramid (Figure 5).

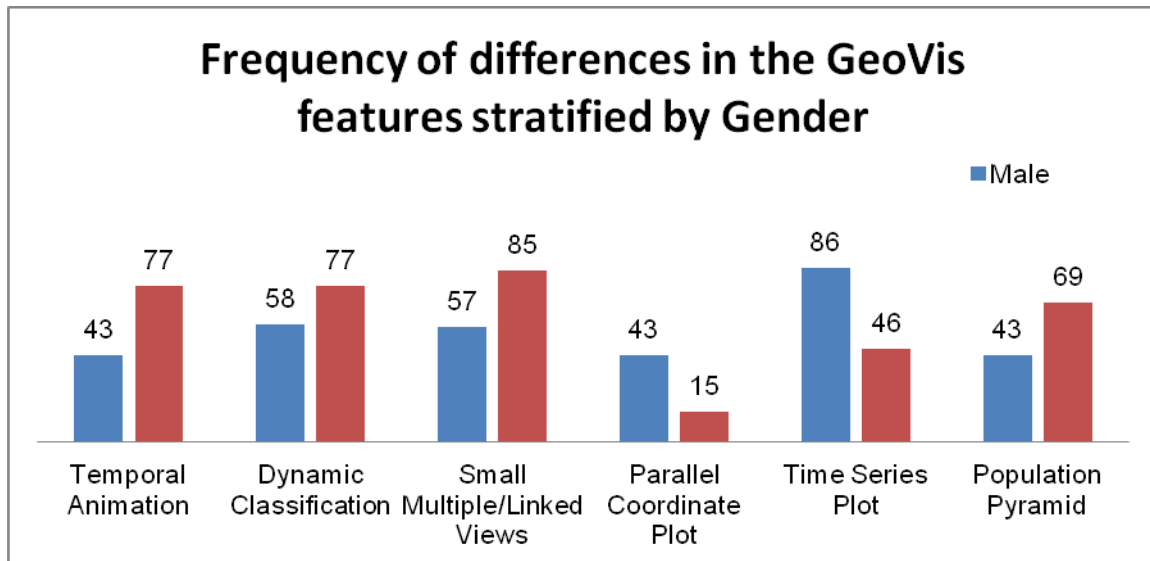


Figure 5. Frequency of GeoVis interaction and representation features stratified by gender

The GeoVis features that were found somewhat to completely irrelevant by the males included parallel coordinate plot, population pyramid and temporal animation (43%), remapping symbols and dot plot (29%) and dynamic classification and choropleth maps (28%). Females found parallel coordinate plot (77%), time series plot (46%), remapping symbols, population pyramid and dot plot (31%), dynamic query filter dynamic bubble plot, bubble map and bivariate map (23%).

(c) By prior spatial skills

Majority of the study participants with either no or minimal spatial skills found ability to do comparison of various variables as an important feature of the GeoVis application. More than half of those participants with no or minimal spatial skills found multiple views, aggregation, box plot and tables as relevant features of the GeoVis application. Zooming, brushing, linking and extraction were other relevant features.

Those with basic Geographic Information Systems (GIS) skills for spatial analysis found zooming, linking, suppression, multiple views and bar chart to be very relevant. More than half of them also found comparison, brushing, extraction, aggregation, dynamic classification; scatter plot, box plot, bubble plot, charts and tables as other relevant features of the GeoVis application.

Hundred percent of the participants who used maps but used others for GIS skills found sorting as the most relevant feature of the GeoVis application. Similarly more than half of them found zooming, comparison, choropleth map and charts as other relevant features. Results showed that majority of the participants based on their prior spatial skills found only about half of the GeoVis features relevant to them. These results indicate that specific GeoVis features need to be tailored to individuals with different prior spatial skills (Figure 6).

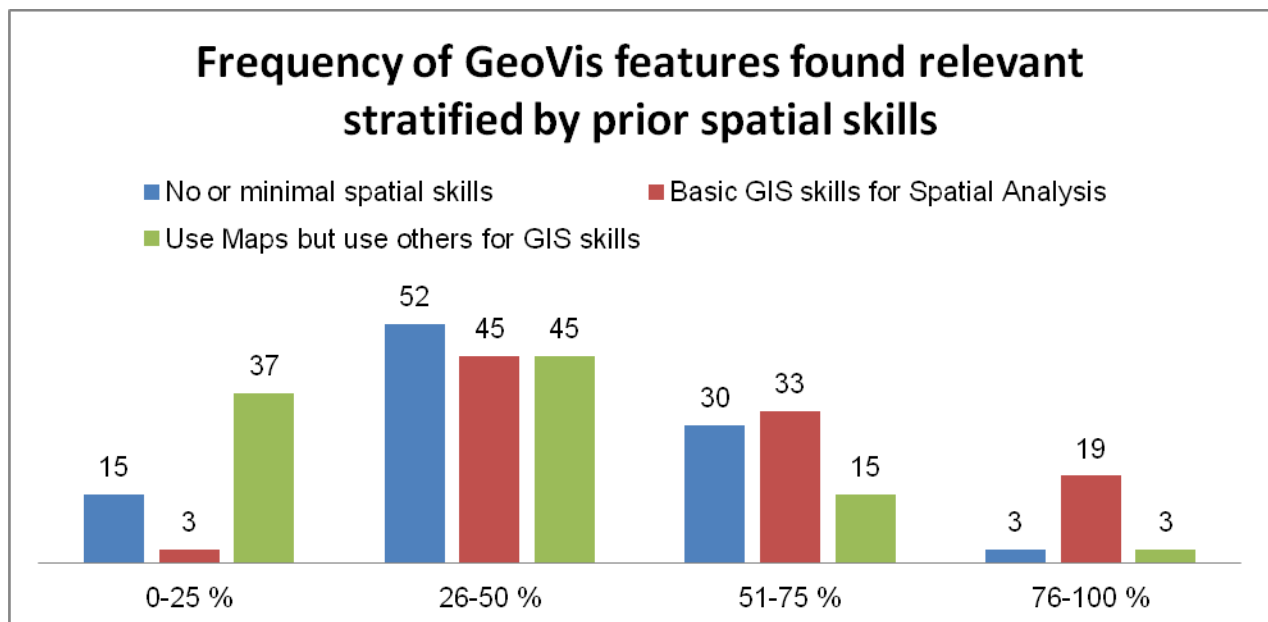


Figure 6. Frequency of relevant GeoVis features stratified by prior spatial skills. The categories 0-25%, 26-50%, 51-75% and 76-100% reflects a range of the frequency of study participants finding GeoVis features relevant.

Parallel coordinate plot was not found relevant by any of the study participants either with no or minimal spatial skills or those that had basic GIS skills for spatial analysis.

(d) *By prior GeoVis familiarity*

All the study participants with no prior GeoVis familiarity agreed that ability to do comparisons across different variables as an important feature of the GeoVis application. Zooming, sorting, linking and extraction were other relevant GeoVis features for these study participants. More than half of them considered Scatter and box plot useful representation features of the GeoVis application. Population pyramid, dot map, parallel coordinate plot, toggling, remapping symbols and temporal animation were considered the other least relevant GeoVis among all the study participants with rare GeoVis familiarity.

Those participants that rarely had any prior GeoVis familiarity found zooming and sorting as important interaction features and found bubble plot, choropleth map and bivariate map as preferred representations.

For those participants who were occasional users of prior GeoVis application, zooming, comparison, brushing and linking were considered important. Choropleth map, tables and charts were the preferred representations for these participants. Temporal animation, remapping symbols, toggling, box plot, bubble plot, parallel coordinate plot, time series plot and dot map were considered least relevant features among the participants with occasional prior GeoVis familiarity.

(iv) *Sketching results*

We counted the number of features that were most commonly identified in the sketching drawn by diverse user groups (Figure 7&8).

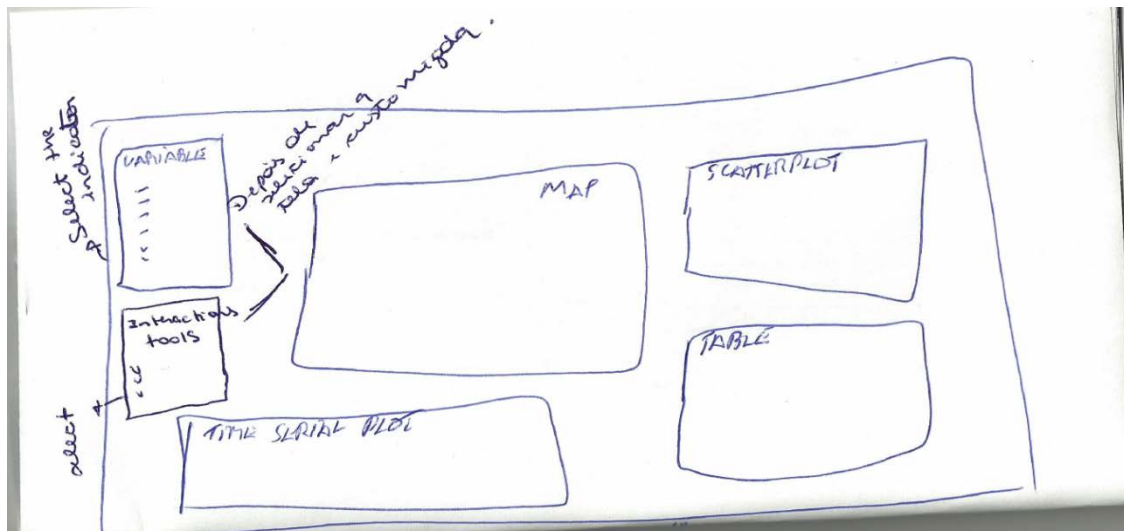


Figure 7 Sketching example

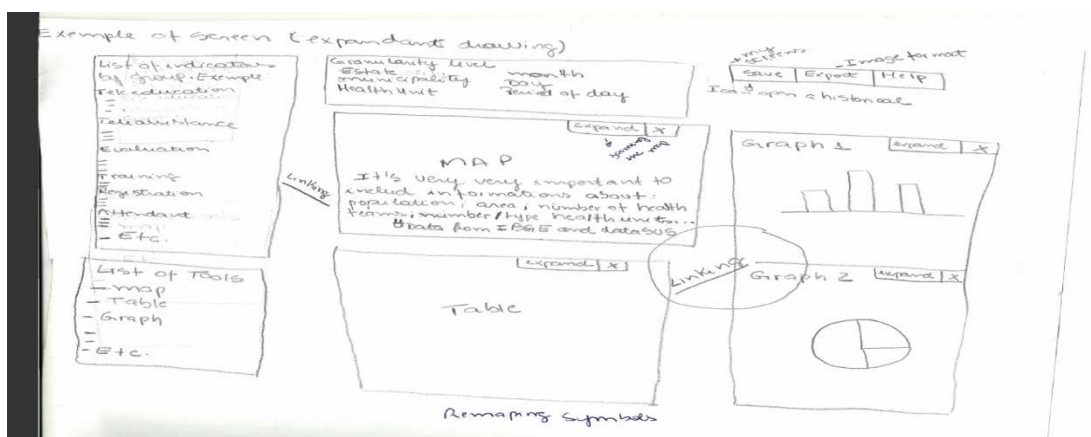


Figure 8. Sketching example

Results found linking (70%; n=14), comparison (65%; n=13); time series (45%; n=9) and multiple views (45%; n=9) as the most preferred GeoVis features (Figure 9). Sorting and highlighting were the other common preferred GeoVis features. Choropleth maps and tables were the most common preferred representation features.

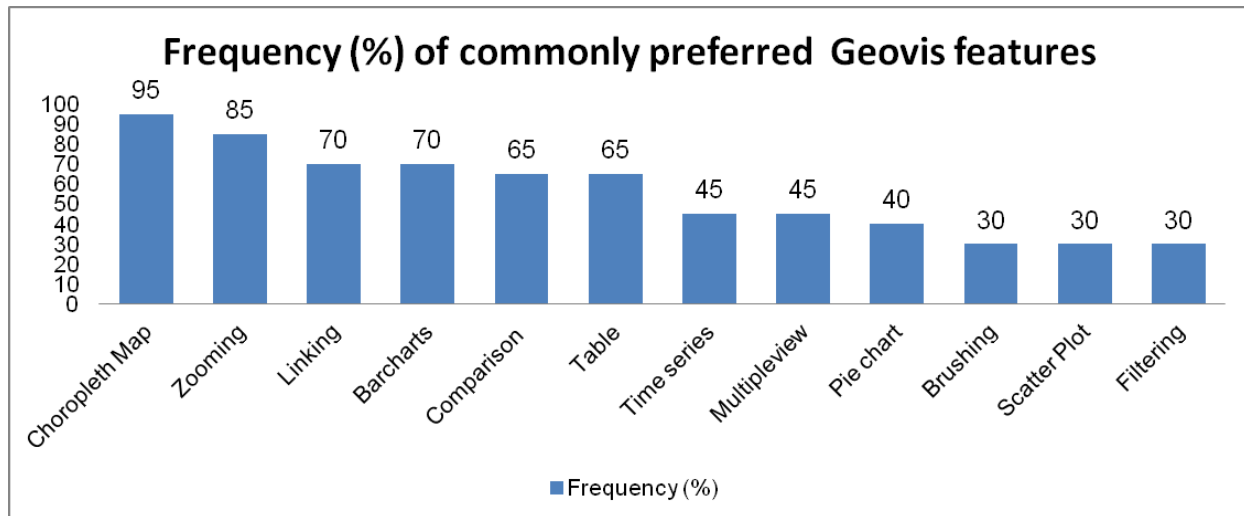


Figure 9. Results of sketching showing commonly preferred GeoVis features

Some of the features that were less preferred included remapping symbols (20%; n=4), aggregation (20%; n=4). Box plot (20%; n=4) and sorting (10%; n=2). Toggling (5%; n=1), bubble plot (5%, n=1), population pyramid (5%; n=1) were the least preferred GeoVis features. All of the participants found parallel coordinate plot as the least preferred GeoVis feature.

(v) Results of open-ended Interviews

Results of the open-ended interviews found linking (n=11), zooming (n=11) and brushing (n=11) as important interaction features of GeoVis. Similarly comparison (n=8), multiple views (n=7) and filtering (n=7) were identified as other important features of the GeoVis application. Other features that were found important were tables (n=6), choropleth maps (n=6), aggregation (n=5) and charts (n=5). The features that were found to be least important were bubble plots and dynamic query filter (n=3). Some study participants found time series plot, small multiple linked maps, dot map, bivariate map, temporal animation, remapping symbols, scatter plots and population pyramid as other less relevant features. None of the study participants found parallel coordinate plot to be relevant. The results of the open-ended interviews were in concordance

with the quantitative assessments of the features that might be necessary for the design and development of the human centered GeoVis system the “SanaViz”.

The participants expressed their interest to compare the multiple variables, find correlation between them and should be able to rank the health unit centers or municipalities based on their participation in the telehealth sessions. Majority of the participants recommended that the interface should be able to be customized based on their needs and some information should be available for each interaction feature so that users know about the utility of that particular interaction. One of the participants indicated that *“the system must be self explanatory, should show what each indicator is because some people don’t know. Moreover, I think it is important that the system has three types of predefined templates for e.g. a template for the statistical person, another to the Telehealth management team and another to the health professionals and managers from the municipalities”*. For e.g., *“person can have three icons and each one of them can be clicked based on their role and then they customize the presentation based on their needs”*.

“The SanaViz”: Proposed Design of the Human Centered GeoVis application

Results of card sorting, sketching techniques and in-depth interviews provided the necessary feedback to design proposed web enabled human centered GeoVis application “the SanaViz” aimed to facilitate visual exploration of telehealth data. The SanaViz will allow users to perform their tailored tasks based on their needs. The information then can be presented in the format defined by the users (e.g. maps, charts and tables) and applicable to their needs. One important finding was to allow users to see the list of the interaction features that are part of the GeoVis application for better that will help them better utilize their data exploration techniques. This finding was important as most of the study participants agreed that it was difficult for them to use different functions of the of the GeoVis applications as these were not self-explanatory as

observed in other Public Health GeoVis applications.. The initial design of “the SanaViz” is presented based on the various findings of our study and will now be developed and evaluated in the follow up study.

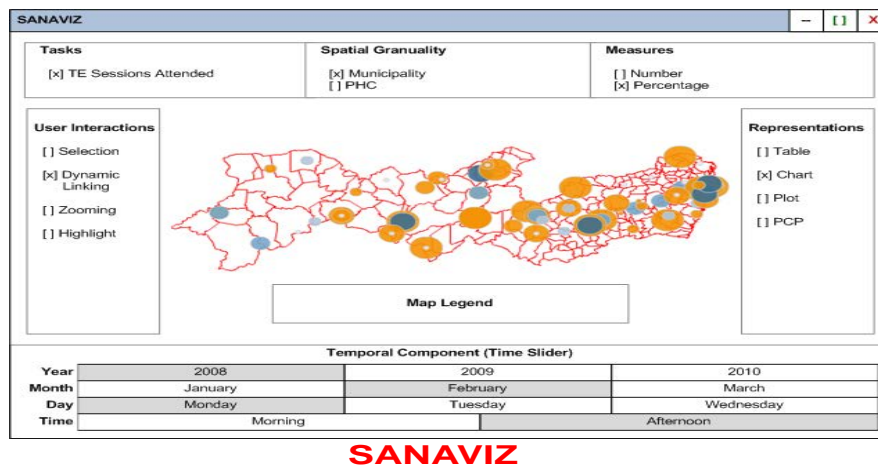


Figure10. Proposed design of the HC GeoVis prototype the “SanaViz”

Discussion

Increasingly complex public health datasets reflect a growing need for methods and tools to support the construction of knowledge (ISO, 1999). GeoVis is being increasingly integrated into Public Health information systems and helps in gaining new insights rather than just communicating something that is already known. Knowledge can be created and revealed through the abstract representations of maps. GeoVis displays events in space and time making possible the perception of where and when. User issues and interface design are common themes in current GeoVis research.

Our usability results found ESTAT and PA-CA atlas to be unnecessary complex and cumbersome to use. Majority of the participants did not find Instant Atlas GeoVis application complex; however; felt that they would need the support of a technical person to be able to use it. Our results found existing GeoVis applications to be difficult and lacked number of the

essential ingredients needed to make GeoVis applications practical for use by typical public-health researchers. Results of a prior study have shown that different map types are useful for different purposes and for satisfying the varying individual skill level (Cinnamon et al., 2009).

The results of our study described the perception of the telehealth users towards existing GeoVis applications utilized in public health. Further the methods of card sorting and sketching helped us identify the key features that are necessary to be part of the proposed Human Centered, web enabled GeoVis application “the SanaViz”.

There is limited guidance for the design of usable GeoVis applications. Their design requires knowledge about the context of work within which they will be used, and should involve user input at all stages, as is the practice in any human-centered design effort. It is important to use real data both to gain engagement with users and to help them learn about the nature of GeoVis techniques.

Results of our card sorting found zooming (75%; n=15), linking (70%; n=14) and brushing (65%; n=13) as very relevant interactions and should be part of the GeoVis applications. Highlighting (60%; n=12), aggregation (60%; n=12), multiple views (55%; n=11) and filtering (N=50%; N=10) were other very relevant GeoVis interaction features. Tables (95%; n=19), bar chart (80%; n=16), choropleth maps (75%; n=15), linked views (75%; n=15) and bubble plot (70%; n=14) were found to be preferred methods of representation of the data.

Results of the card sorting, sketching and the open ended in-depth interviews showed similar results among the various user categories involved with the telehealth program. The feedback gathered during this study helps us identify necessary features of the Human centered GeoVis application “the SanaViz” and will help us develop the application for further evaluation among the telehealth users.

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References

- Andrienko, N., Andrienko, G., Voss, H., Bernardo, F., Hipolito, J., & Kretchmer, U. (2002). Testing the usability of interactive maps in CommonGIS. *Cartography and Geographic Information Science*, 29(4), 325-342.
- Aigner, W., Miksch, S., Mueller, W., Schumann, H., & Tominski, C. (2007). Visualizing time - oriented data: A systematic review. *Computers and Graphics*, 31, 401-409.
- Arnowitz, J., Arent, M., & Berger, N. (2006). *Effective prototyping for software makers*. San Francisco, Ca: Morgan Kaufmann Publisher (Elsevier).
- Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction*, 24(6), 574-594.
- Bhowmick, T., Griffin, A. L., MacEachren, A. M., Kluhsman, B. C., & Lengerich, E. J. (2008). Informing geospatial toolset design: Understanding the process of cancer data exploration and analysis. *Health & Place*, 14(3), 576-607.
- Bhowmick, T., Robinson, A. C., Gruver, A., MacEachren, A. M., & Lengerich, E. J. (2008). Distributed usability evaluation of the Pennsylvania Cancer Atlas. *International Journal of Health Geographics*, 7(1), 36.
- Bowen, J., & Reeves, S. (2007). Formal models for informal GUI designs. *Electronic Notes in Theoretical Computer Science*, 183, 57-72.
- Brooke, J. (1996). SUS-A quick and dirty usability scale. In Jordan PW, Thomas B, Weerdmeester BA, McClelland AL, (Eds.). *Usability Evaluation in Industry*, 189, 194. London: Taylor and Francis.
- Cinnamon, J., Rinner, C., Cusimano, M. D., Marshall, S., Bekele, T., Hernandez, T. Chipman, M. L. (2009). Evaluating web-based static, animated and interactive maps for injury prevention. *Geospatial Health*, 4(1), 3-16.
- Earthy, J. (1999). Usability maturity model: Processes. *Lloyd's Register of Shipping*.
- Faiks, A., & Hyland, N. (2000). Gaining user insight: A case study illustrating the card sort technique. *College & Research Libraries*, 61(4), 349-357.

- Fuhrmann, S., Ahonen-Rainio, P., Edsall, R. M., Fabrikant, S. I., Koua, E. L., Tobón, C., . . . Wilson, S. (2005). Making useful and useable geovisualization: Design and evaluation issues. *Exploring Geovisualization* (November 2004), 551-566.
- ISO. (1999). 13407: Human-centered design processes for interactive systems. Geneva: ISO.
- Jamison, D. T. (2006). Disease control priorities in developing countries. Washington, DC: Oxford University Press.
- Johnson, C. M., Johnson, T. R., & Zhang, J. (2005). A user-centered framework for redesigning health care interfaces. *Journal of Biomedical Informatics*, 38(1), 75-87.
- Kushniruk, A. W., Patel, V. L., & Cimino, J. J. (1997). Usability testing in medical informatics: Cognitive approaches to evaluation of information systems and user interfaces. *Proceedings from the AMIA Annual Fall Symposium*, 218.
- Lloyd, D. (2009). *Evaluating Human-Centered Approaches for Geovisualization*. City University of London. Retrieved from: http://openaccess.city.ac.uk/468/1/lloyd_evaluating_2009.pdf.
- Muntz, R., Barclay, T., Dozier, J., Faloutsos, C., Maceachren, A., Martin, J., Satyanarayanan, M. (2003). IT roadmap to a geospatial future, report of the committee on intersections between geospatial information and information technology. Washington, DC: National Academy of Sciences.
- Nielsen, J., & Landauer, T. K. (1993). A mathematical model of the finding of usability problems. *Proceedings from the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems*, 206-213. Amsterdam, Netherlands: ACM.
- Richards, T. B., Croner, C. M., Rushton, G., Brown, C. K., & Fowler, L. (1999). Geographic information systems and public health: Mapping the future. *Public Health Reports-US*, 114, 359-373.
- Rivest, S., Bedard, Y., & Marchand, P. (2001). Toward better support for spatial decision making: Defining the characteristics of spatial on-line analytical processing (SOLAP). *Geomatica*, 55(4), 539-555.
- Robinson, A. C. (2005). Geovisualization and epidemiology: A general design framework. *Proceedings from the 22nd International Cartographic Conference. A Coruña, Spain*.
- Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., & MacEachren, A. M. (2005). Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science*, 32(4), 243.

- Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S., & Hedley, N. R. (2001). Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, 28(1), 61-75.
- Sopan, A., Noh, A., Lee, G., Rosenfeld, P., Karol, S., & Shneiderman, B. (2012). Community health map: A geospatial and multivariate data visualization tool for public health datasets. *Government Information Quarterly*.
- Timpka, T., Ölvander, C., & Hallberg, N. (2008). Information system needs in health promotion: A case study of the safe community program using requirements engineering methods. *Health Informatics Journal*, 14(3), 183-193.
- Tohidi, M., Buxton, W., Baecker, R., & Sellen, A. (2006). User sketches: A quick, inexpensive, and effective way to elicit more reflective user feedback. *Proceedings from the 4th Nordic Conference on Human-Computer Interaction: Changing Roles*, 105-114. Oslo, Norway: ACM.
- Tullis, T. S., & Stetson, J. N. (2004). A comparison of questionnaires for assessing website usability. *Proceedings from the Usability Professional Association Conference*. Minneapolis, USA.
- van der Wilk, E. A., & Verschuuren, M. (2010). Adding value to figures: A web-based European public health information system. *Journal of Telemedicine and Telecare*, 16(1), 35-41.

Evaluating usefulness and effectiveness of Human Centered GeoVisualization prototype “The SanaViz” to facilitate visual exploration of Telehealth data: A case study

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Abstract

Public health system is usually the major provider of health services in developing countries while public health data is typically organized by geospatial unit. The objective of our study was to evaluate the usefulness and effectiveness in performing tasks using Human Centered (HC) GeoVis prototype "The SanaViz" against a conventional GeoVis application Instant Atlas to facilitate visual exploration of telehealth data in Brazil. The SanaViz is an Internet based; bilingual, interactive, Web application aimed at facilitating visual exploration of public health data, and in this context, telehealth data. A cross sectional within-subject study design was utilized. A convenient sample of 20 study participants from diverse backgrounds was enrolled. A mixed methods approach using a combination of qualitative and quantitative assessments was performed. The users were asked to perform 5 tasks using both the GeoVis applications. Univariate analyses were performed to report descriptive statistics including mean and standard deviation for the continuous variables and frequency distributions for the categorical variables. Repeated measures of analysis of variance (ANOVA) was performed on the within-subject design to test for significant differences between the newly developed HC GeoVis prototype application "the SanaViz" and the existing GeoVis application Instant Atlas. NVivo was used to analyze qualitative data. All other analysis was performed using SAS v9.1. Results of our study showed that HC GeoVis prototype "The SanaViz" required less time, was reported as easier, required less assistance, and required fewer attempts than Instant Atlas. The order of using GeoVis prototype did not show any impact on time, ease, assistance, or number of attempts. Future studies are needed to assess the long term use of "The SanaViz" and to determine the changes that might be needed to be made for further improvement of the prototype

Introduction

Public health system is usually the major provider of health services in developing countries while public health data is typically organized by geospatial unit. Limited technology infrastructure, financial constraints, maldistribution of health-care professionals and healthcare facilities are some of the major challenges for providing quality care in developing countries. However, telehealth is proposed as one of the solutions to healthcare problems in developing countries; however one of the major challenges with Telehealth adoption in developing countries is lack of timely evaluation of Telehealth programs. Teleeducation (TE), one of the modalities of telehealth services can be used to provide continuing education to healthcare professionals in developing countries (Knowles, Lewis, King, King, & Jones, 2008). TE has been shown to be effective in the transmission of knowledge to health professionals (Hu & Chau, 1999; Reed, 2005).

Tele-education in Brazil: an Overview

Brazil is a large country confronting many social issues that impede the delivery of healthcare to people living in remote and/or poor areas (Novaes, Mattos, Barbosa, & Soares, 2004). Lack of expertise amongst health professionals in the primary care sector, unnecessary referrals and the difficulty of facilitating consultations with medical specialists led to the development of the Brazilian teleeducation program (Brazilian Telehealth Program, 2011). This TE Program connects primary health care facilities with university centers of reference to improve the quality of services provided in primary care. Pernambuco is a state in northeastern Brazil. It has 185 municipalities and more than eight million inhabitants. Tele-education in primary care began in 2003 via the telehealth network of Pernambuco (RedeNUTES) (RedeNUTES Pernambuco, 2011). In 2008 each primary care facility was provided with telehealth equipment to connect primary health centers to the telehealth centre in Recife. Staff of the TE program provided training to the primary health care facilities. The TE service is provided to primary health care facilities in Pernambuco State and coordinated by the NUTES telehealth centre (Bhowmick, Griffin, MacEachren, Kluhsman, & Lengerich, 2008). Results of our earlier study categorized the

telehealth data as a public health data by three key components including (a) spatial, (b) temporal and (c) attribute (Joshi et al., 2011). The spatial component includes data with location attributes (e.g. address, primary health centers or municipalities), (b) temporal (time) component records time of the observation, and (c) attribute component relates to public health issues of interest. As public health datasets become increasingly complex, there is a growing need for methods and tools to support the construction of knowledge (Bhowmick, Griffin, MacEachren, Kluhsman, & Lengerich, 2008).

GeoVisualization (GeoVis) simplifies large and complex datasets into more comprehensible forms and allow users to see the information visually on a map. Maps are an efficient means for the communication, analysis, synthesis, and exploration, of geographic data and information (van Elzakker, 2003). Visual representations can often communicate information much more rapidly and effectively and can help decision makers prioritize the actions and regulations required for better public health outcomes (Malczewski, 2006). Results of prior studies have shown GeoVis applications to be difficult and lacking number of the essential ingredients to make GeoVis applications practical for use (Wassink, Kulyk, Dijk, Veer, & Vet, 2009). Results of our prior studies have shown that the user model helps to gather individuals' understanding about data, functions, domain and mapping (Joshi et al., 2011; Bhowmick, Robinson, Gruver, MacEachren, & Lengerich, 2008). Mapping understanding of user needs to the system functions is necessary to create a useful and effective GeoVis application (Bhowmick, Robinson, et al., 2008). A Human Centered GeoVis approach facilitates visual exploration of public health data by giving specific considerations to users' knowledge, expertise and use of the interaction techniques to represent tasks performed by the users (Andrienko et al., 2007; Hollan, Hutchins, & Kirsh, 2000; Koua & Kraak, 2004; Zhang & Butler, 2007). Cognitive Fit Theory (CFT) explains how graphical displays affect the decision processes (Dennis & Carte, 1998). When the information presentation matches the task, it produces faster and more accurate results (Dennis & Carte, 1998). If the information does not match the ultimate needs of the task it results in

decreasing accuracy and increasing time because. These benefits translate into system and task related performance factors. Choice of an interaction method and representation is crucial to the success of a GeoVis environment.

The SanaViz: A Human Centered GeoVis prototype

The SanaViz is an Internet based; bilingual, interactive, Web application designed using combined principles of Human Centered (HC) approach and Cognitive Fit Theory (CFT) and is aimed at facilitating visual exploration of public health data, and in this context, telehealth data (Figures 1-3).

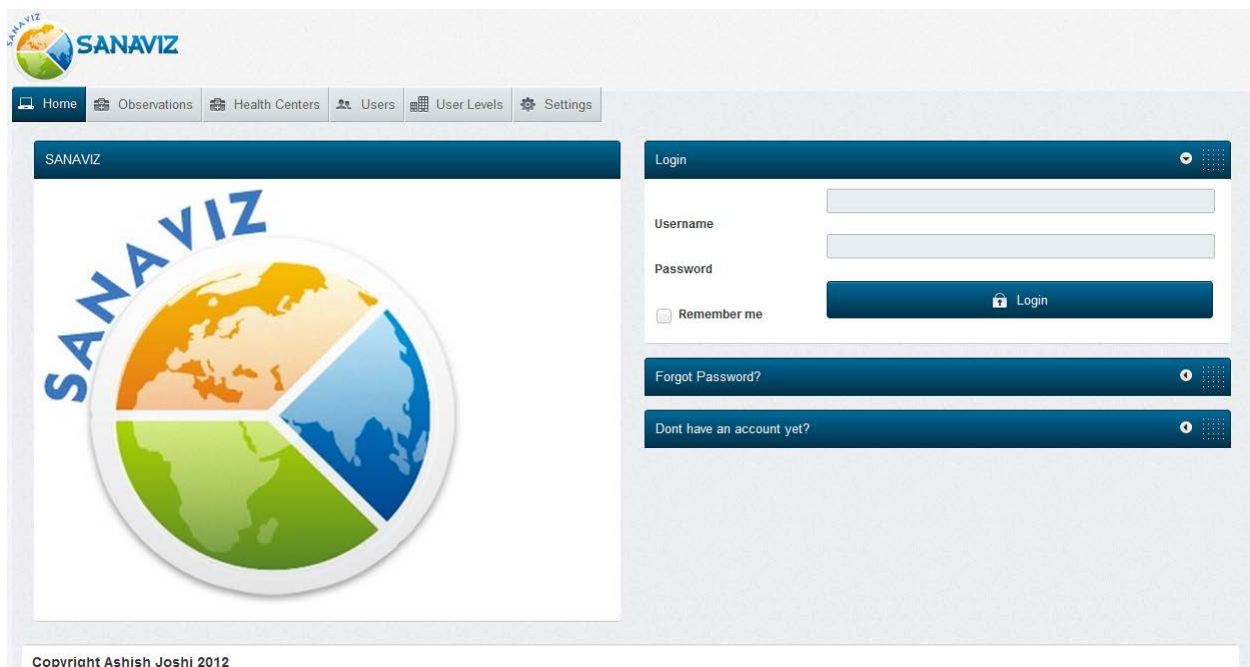


Figure 1. The SanaViz “Log in and Registration View”

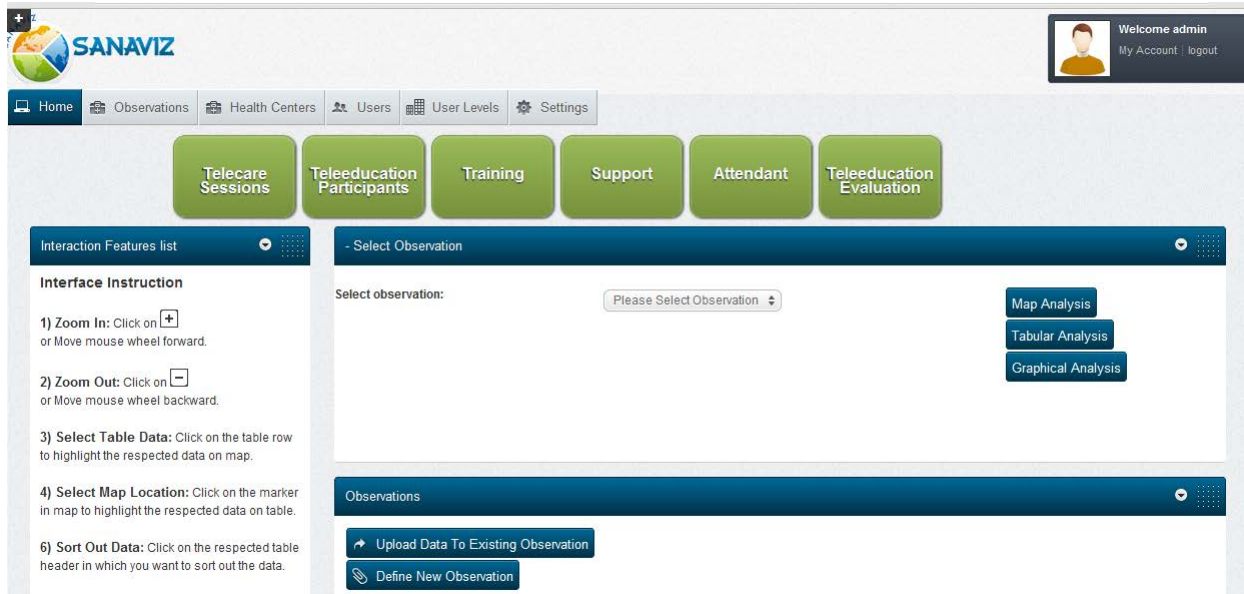


Figure 2. The SanaViz “Exploratory Analysis View”

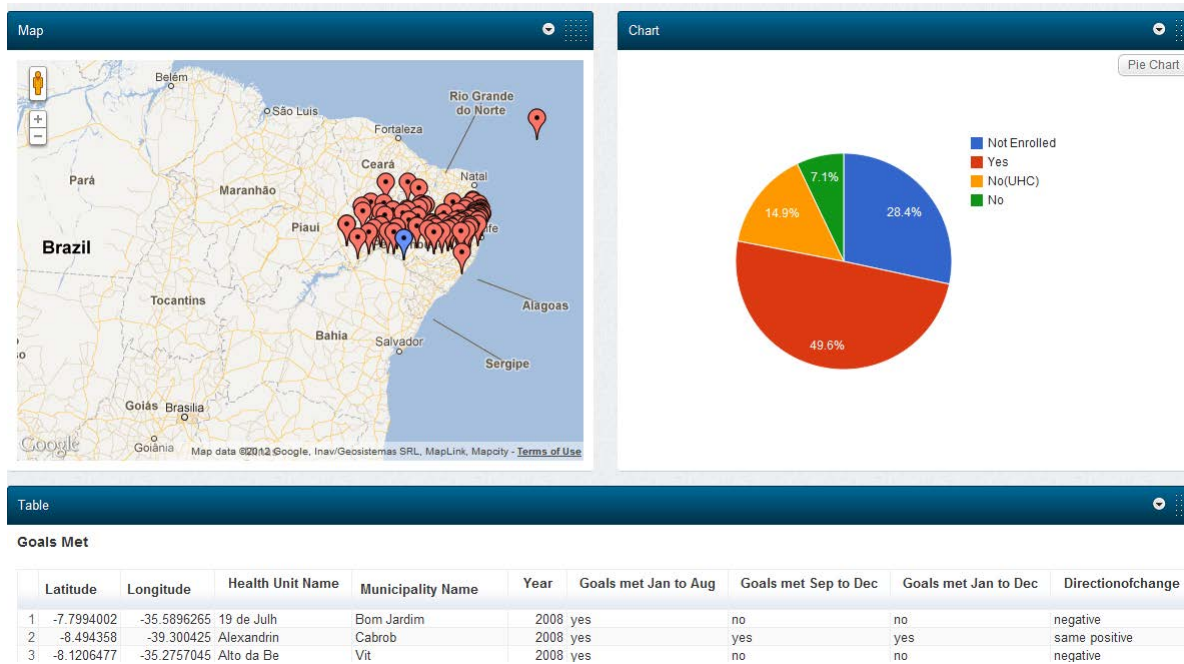


Figure 3. The SanaViz “Results View”

The SanaViz Prototype Components: The prototype has the following components; (a) Log in and Registration Screen: It captures information about the individual users’ age, gender, prior spatial skills, previous use of GeoVis and their role in the telehealth program (e.g. researcher, statistician, software programmer) (Figure1). (b) The user management will facilitate the level of

access controls that the different users will have to operate the prototype. (d) The Data Management allows users to import the data in the excel sheet, update, edit, modify and delete the different observations. (e) The outcome indicators assessment allows users to define the tasks they want to perform specific to their needs. (f) The data view component allows the users to utilize various interaction features to perform exploratory analysis and display results in various representations such as Map, Charts and Tables. The interaction features such as zooming, highlighting, sorting, and multiple linkages provide necessary information to the users to explore their data using different perspectives.

The SanaViz Developmental Platform: The SanaViz is a windows platform and uses Adobe Dreamweaver CS3 for interface design, MySQL 5.1 and SQL queries for database and database functionality, adobe flash for the graphics, and PHP 5.2, JAVASCRIPT, HTML, CSS and Ajax for the overall application including user and data management. Google maps and visualization API are used to show Google maps, chart and table on the analysis screen.

User evaluation of GeoVis applications

User-testing has been useful for creating and implementing GeoVis systems appropriate for public health users. Better GeoVis applications can be created through a usability approach resulting in the creation of systems that are easy to learn, increase productivity and user-acceptance (Slocum, Cliburn, Feddema, & Miller, 2003). Usability-testing refers to the evaluation of information systems with participants who are representative of the target user-population, as they interact with an information technology (Kushniruk & Patel, 2004). Test results are an effective way to determine if the user found the application useful for its needs. Users can be tested together in a group setting, or in individual sessions. One-on-one testing is preferred as it avoids pitfalls related to group dynamics. Individual tests can take the form of task completion scenarios (Cinnamon et al., 2009). The majority of usability issues can often be highlighted from a representative sample which typically involves as few as 8-10 participants (Kushniruk, 2002). Exploration and knowledge discovery support in the visualization

environment can be examined by assessing user performance for a number of defined tasks and goals. The geographical analysis process can be viewed as a set of tasks and operations, needed to meet the goals of the data exploration. The most comprehensive list of tasks includes: identify, locate, distinguish, categorize, cluster, distribution, rank, compare, associate, and correlate (Wehrend & Lewis, 1990). The evaluation of the graphical representations and interfaces needs to be grounded in a task model that can focus more on the user's goals and the tasks he needs to perform (Koua, MacEachren, & Kraak, 2006). Task scenarios ensure that certain interface features are evaluated. The health technology developers often overlook important user-characteristics, tasks, preferences and usability concerns, resulting in systems that generate more confusion than benefits, or simply remain inadequate. (Johnson, Johnson, & Zhang, 2005; Timpka, Ölvander, & Hallberg, 2008).

Prior studies have shown 3 methods of evaluation criteria (Fabrikant, 2001; Shaw, 1996; Sweeney, Maguire, & Shackel, 1993). One of the criteria is (a) Effectiveness that focuses on the application functionality and examines the user's performance for the tasks. This can be measured by the time spent for completing tasks; ease with which the tasks are completed, assistance needed to complete the tasks and the number of attempts taken to complete the tasks. (b) Usefulness refers to appropriateness of the application's functionality and assesses whether the application meets the needs and requirements of the users when carrying tasks. (c) User reactions refer to user's attitude, opinions, subjective views, and preferences and can be measured using open ended questionnaires and in-depth interviews.

The objective of our study was to evaluate the usefulness and effectiveness of HC GeoVis prototype "the SanaViz" against a conventional GeoVis application Instant Atlas to facilitate visual exploration of telehealth data in Brazil.

Study Methods

A cross sectional within subject study design was utilized to enroll a convenient sample of same 20 study participants who had earlier participated in the evaluation of prior existing public health

GeoVis applications and provided their feedback about the essential components of the proposed GeoVis application “the SanaViz”. The study was performed at the NUTES telehealth center, Federal University of Pernambuco (UFPE), during June-July 2012. The participants were from diverse backgrounds to ensure broad representation and included professionals from public health, healthcare, software engineering, computer science, biomedical informatics and statistics. The study participants had diverse roles such as teleconsultants, project management, technical support, administration and statistical analysis. A sample size of 20 participants in this study will be able to detect a within subject difference of 0.8SD (standardized effect size), two tailed and 0.05 level of significance. This study was approved by the University of Texas Health Science Center Institutional Review Board (IRB # HSC-GEN-11-0447).

Study Procedure: A card sorting method was employed by providing participants with a stack of physical 3x5 note cards. One task was labeled on each card and participants were asked to group those tasks for various telehealth indicator categories in a way that made sense to them (Faiks & Hyland, 2000). The five most common telehealth related tasks were identified. Participants were given access to two applications: (a) newly developed HC GeoVis prototype “the SanaViz” and (b) an already existed GeoVis application Instant Atlas. Hereby, we chose Instant Atlas as a comparison because it included features that were most representative of the existing GeoVis applications as found in the prior study. Participants were given 30 minutes to explore both the GeoVis applications in order to become comfortable. After exploring both the GeoVis applications, participants were asked to perform five most representative tasks identified in the study. The order of system usage was randomized to control order effects.

Independent Variable: The two-level independent variable was GeoVis application type (SanaVis, Instant Atlas)

Outcomes assessed: The following outcomes were assessed to compare the two GeoVis applications;

- **Effectiveness:** Focuses on application functionality and examines the users' performance for the tasks. It can be measured by (a) time to complete the tasks, (b) ease with which the task is completed, (c) assistance needed during the tasks and the number of attempts taken to complete the tasks (Kelsey & Rinner, 2009). The ease with which the tasks were completed was gathered on 5 point Likert scale ranging from 1 to 5 (fail/ /hard/medium/easy/very easy).
- **Usefulness:** System Usability Scale (SUS) method is a 10 item questionnaire that refers to appropriateness of the application's functionality that assesses whether the application meets the needs and requirements of the users when carrying the tasks and the extent to which users view the application as supportive for their goals and tasks (Brooke, 1996). The questions consist of close ended questions answered on a five point scale of "Strongly agree" to "Strongly disagree". SUS yields a single number representing a composite measure of the overall usability of the system being studied. To calculate the SUS scores, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items, 1, 3, 5, 7, and 9 the score contribution is the scale position minus 1. For items, 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of system usability. SUS scores have a range of 0 to 100. Majority of the prior studies have shown that a system with a SUS score of 68 to have greater usability (Bangor, Kortum, & Miller, 2008).
- **User reactions:** We performed in-depth interviews to gather feedback about the users' experience of using GeoVis applications "the SanaViz" and Instant Atlas. Feedback was gathered about the various features of GeoVis that needed to be modified or redesigned.

Statistical Analysis: Univariate analyses were performed by investigators to report descriptive statistics including mean and standard deviation for the continuous variables and frequency distributions for the categorical variables. Repeated measures of analysis of variance (ANOVA) was performed on the within-subject design to test for significant differences between the newly developed HC GeoVis prototype application “the SanaViz” and the existing GeoVis application Instant Atlas. Participants were measured repeatedly on several variables, so we used a method of statistical analysis that accounts for the correlation between repeated measurements. Repeated measures ANOVA is a method for testing if the differences between the means differed by GeoVis applications and the tasks. The analysis for Ease, Assistance, and Number of Attempts were based on a generalized version of the ANOVA model (sometimes called generalized estimating equations) that accounts for repeated measures when the dependent variable is not continuous. Ease is ordinal, assistance is binary, and number of attempts is a count (Poisson distribution). NVivo was used to analyze qualitative data. All other analysis was performed using SAS v9.1.

Results

Socio-demographics

The average age of the participants was 28 years (SD=7) and was evenly distributed from young adult to middle age. Majority of them were females (65%) and 90% of them were graduate professionals while the 10% were students majoring in statistics. Almost 100% of the professionals were ranging from somewhat to very familiar with the use of computers. Only 1 (5%) participant was a regular user of GeoVis applications compared to 35% (n=7) that were occasional users. Google maps were the most common GeoVis application that the users were familiar with. A majority of the participants reported that they had no or minimal spatial skills (70%, n=14). Hundred percent of them agreed telecare as one of the most common indicator category. The others have been outlined below (Figure 4).

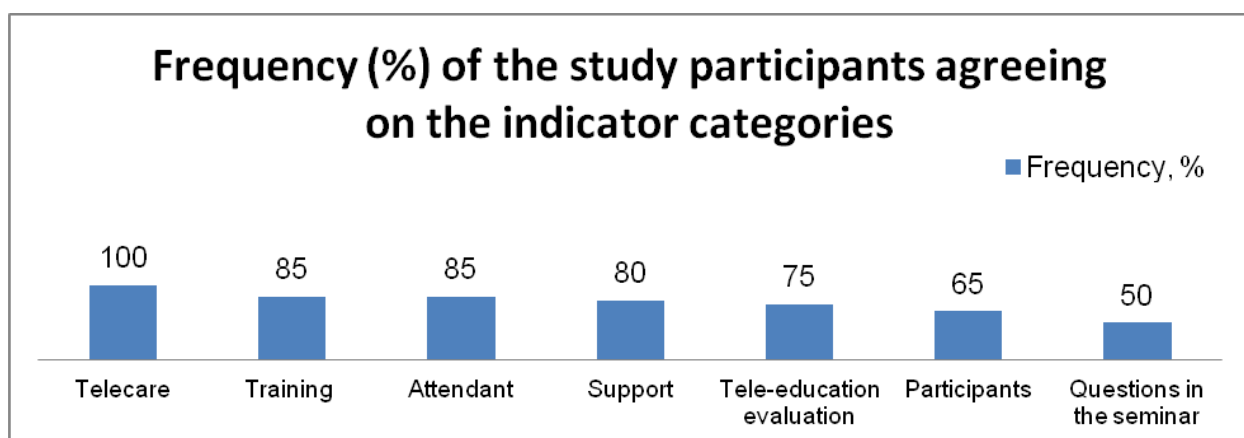


Figure 4. Frequency of the most common telehealth indicator categories

Additional indicator categories that were identified included teleeducation sessions and register attendant team (30%; n=6); teleeducation and registration (25%; n=5); teleeducation participants (20%; n=4); technical problems (10%; n=2); and telehealth services, evaluation, support equipment, video collaboration team, other participants, global evaluation, diagnosis, seminar evaluation and teleattending (5%; n=1). A consensus was reached following discussions with the telehealth users on how to classify indicators to various categories. The final indicator categories were the following;

- (a) Telecare (teleeducation sessions, teleeducation, telehealth services)
- (b) Participants (teleeducation participants, other participants)
- (c) Training
- (d) Support (support equipment, video collaboration team)
- (e) Attendant (Register attendant team, registration)
- (f) Tele-education evaluation (evaluation, seminar evaluation, global evaluation, questions in the seminar, technical problems, diagnosis)

Results showed no differences in the various telehealth indicators when stratified by user categories (telecare $p=0.67$; participants $p=0.32$; training $p=0.09$; support $p=0.78$; attendant $p=0.59$; and teleeducation evaluation $p=0.58$), by gender (telecare $p=0.45$; participants $p=0.06$;

training $p=0.95$; support $p=0.64$; attendant $p=0.27$; and teleeducation evaluation $p=0.27$), by prior GeoVis familiarity (telecare $p=0.11$; participants $p=0.12$; training $p=0.46$; support $p=0.72$; and attendant $p=0.44$) and by spatial skills (telecare $p=0.8$; participants $p=0.24$; training $p=0.51$; support $p=0.58$; attendant $p=0.62$; and teleeducation evaluation $p=0.62$). All the participants across all the categories of GeoVis familiarity had agreed on teleeducation evaluation as the most important telehealth indicator.

A total of 94 unique tasks were identified and were assigned under different telehealth categories. Majority of the tasks were categorized under evaluation ($n=82$), followed by telecare ($n=69$), participants ($n=59$), training ($n=54$), attendant ($n=52$) and support ($n=36$). There was some overlap of the tasks that the users identified among the different indicator categories (Table 1). Majority of the tasks overlap was seen for training, support, telecare and attendant categories (Table 1).

# of tasks overlapped	Participants	Training	Support	Telecare	Attendant	Evaluation
10		X	X	X	X	
9		X			X	
9			X	X	X	
8	X	X	X	X	X	X
8			X	X		
8	X		X	X	X	

Table 1. Number of tasks overlapped among the various telehealth indicator categories. Here X indicates the indicator categories that had overlap tasks

Analysis was also performed to examine the methods of presentation of various tasks including spatial (maps), spatiotemporal (maps, table, graph and plot), temporal (table, graph and plot).

Results showed that majority of the tasks for all the telehealth categories had spatiotemporal relevance (Figure 5). The study participants felt that information should be presented on maps along with table and charts for better understanding of these tasks. 82% of the tasks under the telecare category were mostly identified relevant to have the map presentation along with tables and charts. Reporting included presentation of tasks as table, graph and plot and was mostly preferred for tasks under the evaluation category (Figure 5).

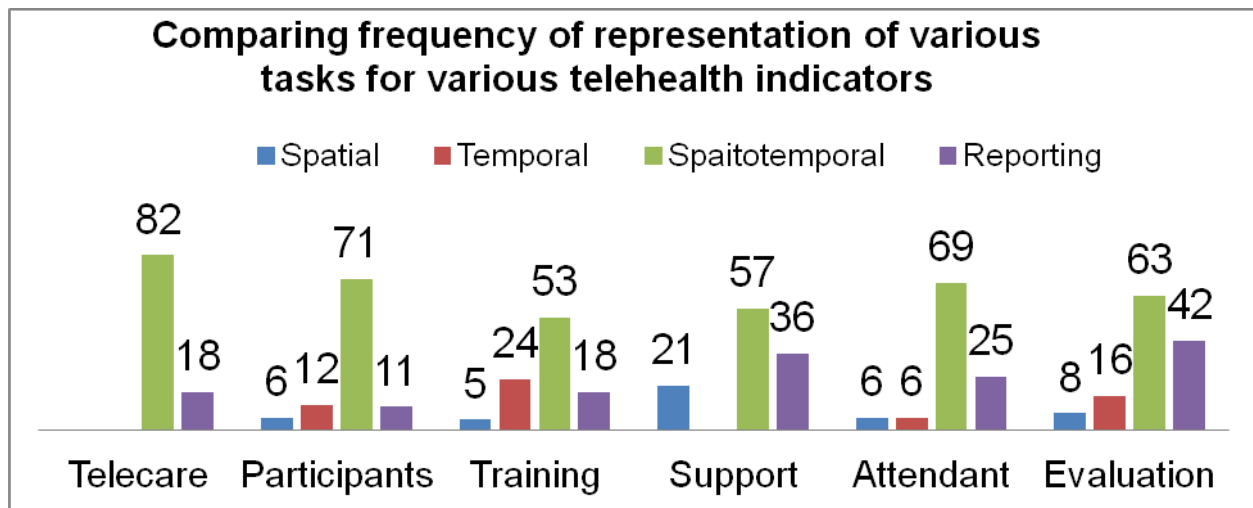


Figure 5. Frequency comparisons of representation of tasks for various telehealth categories
Following outcomes were assessed:

(a) Tasks completion time

For all tasks, Instant Atlas took more time than SanaViz. Instant Atlas, Task 1 took by far most time. The amount of time required was markedly lower at Task 5 when compared to Task 1 (Table 2).

Tasks	SanaViz Mean (SD)	Instant Atlas Mean (SD)	Mean Difference (Std Error)	p-value
Task1	42.55 (23.87)	81.85 (46.52)	-39.3 (9.01)	0.0001
Task2	33.5 (17.43)	42.5 (27.83)	-9.0 (3.59)	0.02
Task3	28.6 (12.07)	40.7 (17.4)	-12 (3.45)	0.002
Task4	17.75 (7.52)	37.55 (25.8)	-19.8 (5.73)	0.003
Task5	12 (6.13)	15.5 (8.11)	-3.5 (0.73)	0.0001

Table 2. Individual comparisons for time by task and GeoVis applications

Results showed that the F test for the repeated measure Task was significant ($F=28.62$; $p=0.0001$) suggesting that overall certain tasks required more (or less) time than others. The

overall statistics for the GeoVis applications was also significant meaning that there were overall significant differences between both the GeoVis applications SanaViz and Instant Atlas ($F=30.16$; $p=0.0001$). Finally, the Task by System interaction was significant ($F=8.26$; $p=0.01$ for task*GeoVis application). This means that the difference between the tasks completion times for the GeoVis applications was not the same for all tasks. Task 1 took significantly more time than Task 2 ($p<0.02$). The overall difference between Task 2 and Task 3 was not significant ($p=0.06$).

GeoVis application by task interaction to evaluate differences between tasks for each GeoVis application was performed separately. SanaViz took less time than Instant Atlas for all Tasks. The difference was not constant (consistent with the significant interaction term as described above). Task 1 took significantly more time than either task 4 or 5 under SanaViz. For Instant Atlas, the difference between tasks 1 and all other tasks were significant. There was a wide time difference between GeoVis applications at task 1 and a comparatively small difference at task 5 (Figure 6).

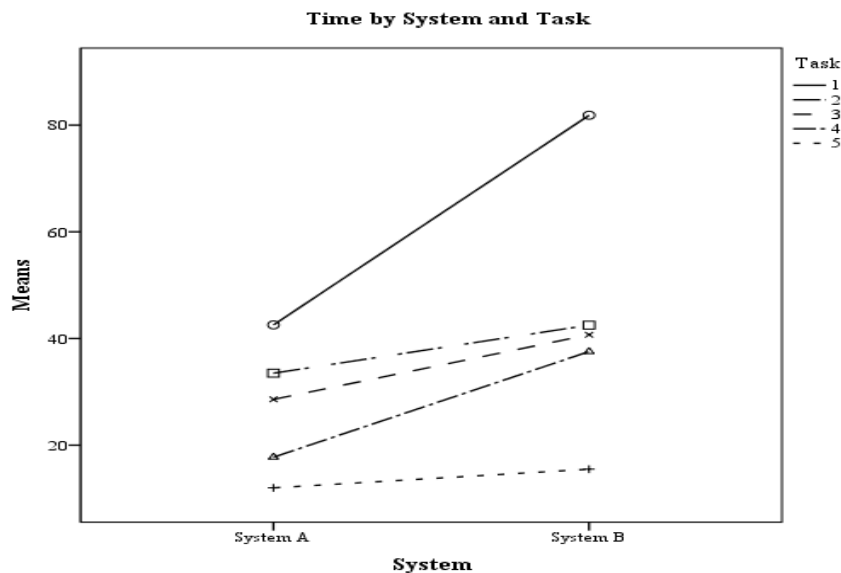


Figure 6. Time by GeoVis system and Task (Here System A is The SanaViz and the System B is Instant Atlas).

(a) Ease of Task completion

The first step was to test for the effect of order. The results was non-significant (Wald Chi-Square= 0.11; $p=0.73$) reflecting that order did not influence ease of Task. Instant Atlas was generally considered harder for most tasks. The group means were identical for task 5. The interaction term was non-significant. Each Task represents a statistical comparison of each Task to Task 5. A direct comparison of means is not recommended due to the multinomial distribution of ease of task. The results showed that each task differed from task 5 overall. Task 5 was lower (easier) than the other tasks (Table 3).

Parameter	Estimate (Std error)	95% CI	Wald Chi-Square	df	p-value
Task1	20.41 (0.49)	(19.44; 21.38)	1717.37	1	0.0001
Task2	18.44 (0.56)	(17.34; 19.55)	1067.44	1	0.0001
Task3	18.75 (0.57)	(17.65; 19.87)	1101.65	1	0.0001
Task4	19.06 ^b				

Table 3. Individual statistical test for ease by GeoVis applications and Tasks.

^bSingularity is caused by this parameter. There is no information in the row for Task 4. The reason for this is that the ease scores for Task 3 and Task 4 are identical under SanaViz (they are all “easy”). When the values are identical, the computer cannot distinguish between these two tasks, so the formal statistical test for task 4 is redundant.

(b) Assistance needed to complete the tasks

The order did not have a significant impact on the assistance needed to complete the tasks (Wald Chi Square=0.766; $p=0.38$). Instant Atlas required more assistance, especially with the first few tasks. The amount of assistance required dropped for both SanaViz and Instant Atlas from task 1 to task 5. There was overall significant difference for assistance needed by GeoVis applications (SanaViz and Instant Atlas) (Wald Chi-square=11.29; $p=0.001$) and Task (Wald Chi-square 5069.6; $p<0.0001$). The interaction term for System by Task was non-significant. Instant Atlas required more assistance than SanaViz. Results of individual comparisons for assistance by task showed that Task 1 required significantly more assistance than tasks 2, 3, 4, or 5 (Table 4).

Task	Task	Std error	p-value
1	2	0.079	0.007
	3	0.094	0.024
	4	0.081	0.034
	5	0.094	0.003
2	1	0.079	0.007
	3	0.046	1.00
	4	0.048	0.419
	5	0.036	0.063
3	1	0.094	0.024
	2	0.046	1.00
	4	0.042	0.353
	5	0.029	0.020
4	1	0.081	0.034
	2	0.048	0.419
	3	0.042	0.353
	5	0.048	0.027

Table 4. Individual Comparisons for Assistance by Task

(a) Number of attempts

The variable reflects a numeric count and the effect of order was non-significant on the number of attempts (Wald Chi-Square=0.389; $p=0.533$). Overall, Instant Atlas required more attempts than SanaViz. Tasks 1 and 2 tended to require more attempts than task 5. There was a large difference between SanaViz and Instant Atlas at task 1. The magnitude of that difference was markedly smaller for other tasks, and there was no difference between SanaViz and Instant Atlas at task 5. The main effect of GeoVis application was significant (Wald Chi-square=10.49; $p=0.001$). Overall, there was a significant difference between SanaViz and Instant Atlas on number of attempts. Similarly the main effect of task was also significant (Wald Chi-square=12.71; $p=0.013$) reflecting that there were overall differences among the tasks. The interaction of GeoVis application and Task was significant (Task* GeoVis application Wald Chi-square=13.38; $p=0.01$) reflecting that there were larger differences between the GeoVis

applications for some tasks but not others. SanaViz and Instant Atlas GeoVis applications differ at task 1 ($p=0.01$) for the number of attempts but is non-significant for Tasks 2-5.

Stratified analysis by Gender, GeoVis familiarity and spatial skills

The women tended to take more time responding regardless of system or task ($p<0.04$). The time scores tended to decrease from task 1 to task 5. No gender differences were seen in the ease of completing the tasks ($p=0.07$). Both men and women needed assistance for Instant Atlas, task 1. No assistance was needed for task 5 for either system. No gender differences were seen for the attempts that were taken to complete the tasks for Instant Atlas ($p<0.08$).

However, there were slight differences for ease of use by degree of geo visual familiarity and spatial skills. The data suggested that Instant Atlas task 1 was hard for all groups with varying degree of GeoVis familiarity. The ease of task scores dropped considerably from task 1 to task 5 ($p<0.05$). Those who reported “Never” or “Occasional” to Geo Visual Familiarity tended to need assistance with Instant Atlas, task 1. However, the need for assistance decreased from task 1 to task 5. There were slightly more attempts taken to complete task1 for Instant Atlas. There were slightly more attempts at Instant Atlas task one for the occasional GeoVis familiarity group. The number of attempts was elevated for Instant Atlas task 3 among the never GeoVis familiarity group. Instant Atlas, task 1 required a similar level of assistance among those with no, minimal, or map user skills. There were no marked differences among groups with respect to the need for assistance for Instant Atlas task 1. The number of attempts was elevated for those with minimal or basic spatial skills at Instant Atlas tasks 1, 2 and 3. Overall, the most common number of attempts was 1. Results showed no significant differences for the effect of order on time ($F=1.87$; $p=0.18$) indicating that the order in which both the GeoVis applications (SanaViz or Instant Atlas) were used, it did not play a role in the amount of time required to complete the tasks.

B. Usefulness

Results found SanaViz to have significantly higher SUS scores against Instant Atlas (SUS=81 versus 53) ($p=0.002$) (Figure 7).

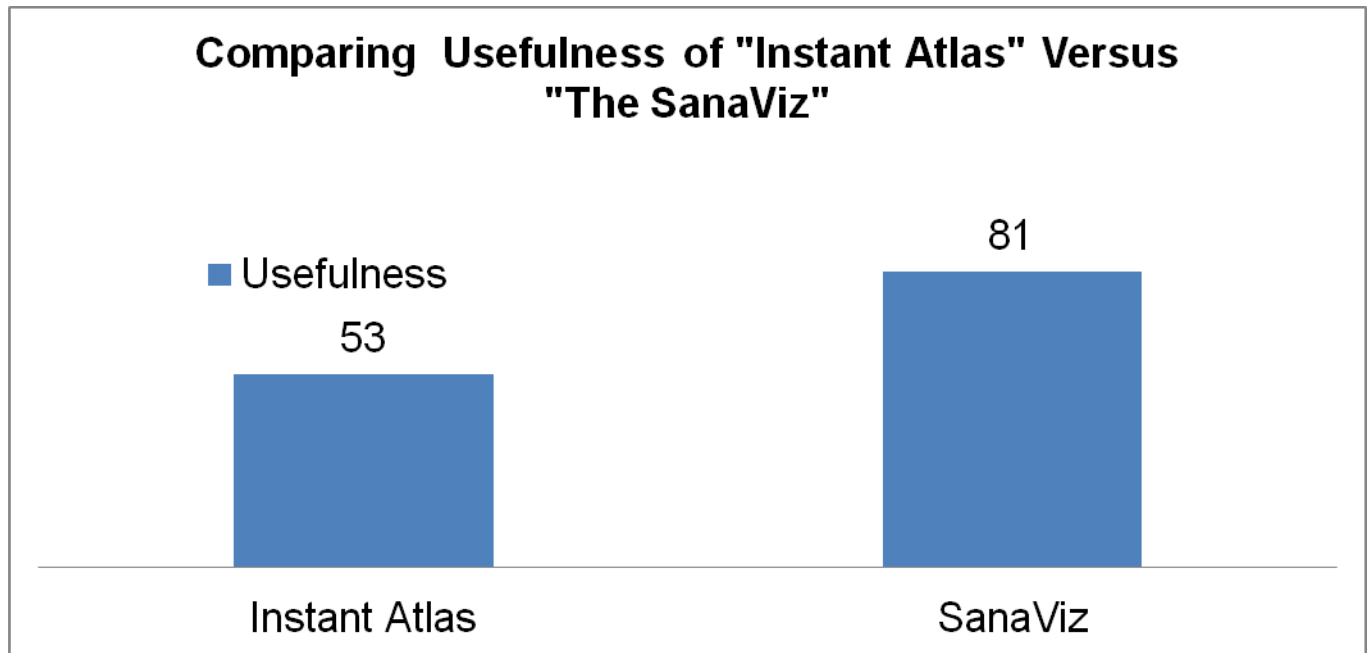


Figure 7. Comparing usefulness of Instant Atlas versus The SanaViz

Results of the stratified analysis by SUS score of 68 and above versus those below 68 showed that 85% ($n=17$) of the study participants scored SUS above 68 or above for the HC GeoVis prototype "the SanaViz" as compared to the 30% ($n=6$) for Instant Atlas.

(C) User reactions

In-depth interviews were performed to evaluate users' opinions about the features that were useful and needed modification.

GeoVis features preferred

Results showed that majority of the participants found "The SanaViz" easy to use as it was easier to find information especially the information about the various indicators. The users found it more comfortable to use GeoVis prototype "The SanaViz" because all the information about the indicators is easy to locate, interface is much cleaner and the interaction features is

right in front of them so they can better explore the data. Majority of the participants found *“the buttons that indicated the presentation of telehealth indicators were easy to see because it was not like the drop down as seen in Instant Atlas”*. One of the participants liked the ability *“to select the data directly in the chart and handle it separately”*. Participants felt that the *“indicator buttons as shown in SanaViz is a way to organize a data so it is good for the manager as a user”*. Majority of the participants felt that *“the administrative panel that allowed users to add, edit or delete the health centers as very useful feature since it gave them direct access to manage the data also”*.

GeoVis prototype “The SanaViz” features that need to be modified

The participants would like to use “The SanaViz” prototype more before able to suggest more improvements. However, some changes that were recommended by the participants included the following: (a) having a much clearer icon that reflects the sorting function in the table, (b) reduce the size of the buttons, boxes and box headers on the registration screen, (c) able to personalize the information like table, charts and maps on the first screen and then on the second screen able to see what they have chosen (d) more filters on the table like excel filters and (e) queries of different analysis can be saved (save query feature). Majority of the participants wanted to have the system in both languages such as *“English and Portuguese”*. Majority of the participants also suggested having the ability to select a particular time period of their choice to select the analysis they want. One of the participants also suggested having the button “Select observation” bigger and more highlighted or evident when the participant selects it. Instructions should be provided to orient the participants about step by step instructions to “View Result”. The *“indicator buttons should get highlighted when a particular indicator button is selected”*. A text button where the participants can type the name of the health centers can be very helpful as majority of the participants were more familiar with this kind of search rather than sorting the health centers by alphabetical names. Majority of the participants also felt that the *“ability to analyze more indicators in the table would be very useful”*. Some of the participants

also felt that *“all the representation features such as tables, maps and chart should be able to fit on the screen and there should be no need to scroll the screen”*. One of the participant also felt that *“an external function to check data validity and inconsistencies should also be integrated”*.

Preferred GeoVis prototype (The SanaViz versus Instant Atlas)

About 95% (n=19) of the participants would prefer to use GeoVis application “The SanaViz” to explore telehealth data and able to visualize their data on maps, tables and charts. Majority of the participants agreed to use “The SanaViz” on a daily basis because *the “information on the screen is clean; I would like to use the system everyday in my activities”*. However some of the participants preferred to use it 3 times a week or on a monthly basis. More than half of the participants liked having Google maps as a part of “The SanaViz” as they were more familiar with it. I prefer SanaViz *“because I feel more comfortable and I see all the indicators in the same screen rather than to scroll down in the drop down as in Instant Atlas”*. One of the participants however recommended including the feature of highlighting the points on the map when the individual brings a mouse cursor over the information in the table as in Instant Atlas. One of the participants preferred Instant atlas because they could see all the information in the same screen and need not use the scrolling. SanaViz is preferred because *“more easy to find the interaction features that we want and can better self guide us on how to explore the data. The system can be more interesting for majority of health professionals because they don’t have ability in informatics”*. Further the ability in “The SanaViz” to upload our data and see indicators altogether makes it very easy to use”

Discussion

Results of our study demonstrate that GeoVis prototype “The SanaViz” using combined principles of Human Centered approach and Cognitive Fit Theory can be used to design and develop a system that models the characteristics and tasks of the users, thus increasing user

effectiveness and user satisfaction. Understanding the users, the domain, and their tasks has the promise to assist in providing quality health care systems.

Results of our study showed that there was a significant difference between systems was supported by this data. The SanaViz required less time, was reported as easier, required less assistance, and required fewer attempts than Instant Atlas. Results of our study also showed that there was no impact of order of using GeoVis prototype (The SanaViz first and then Instant Atlas and vice versa) on time, ease, assistance, or number of attempts that were taken to complete the tasks. Further our results showed significant differences by task as Task 1 tended to require more time, be more difficult, required more assistance, and had more attempts. Results also showed greater user preference for the SanaViz. Further the user evaluation of the HC GeoVis application “the SanaViz” provided feedback about the modifications that might be need to further make the system easy to use. However, results of our study show that early user involvement in the design of the system can facilitate better adoption of GeoVis applications despite lack of prior GeoVis familiarization and prior spatial skills.

Prior studies have shown that limited guidance exists on how to actually design simple, functional GeoVis applications for use in the public health realm (Robinson, Chen, Lengerich, Meyer, & MacEachren, 2005). GeoVis applications are difficult to learn and use, are predominantly generic, do not address specific users and are designed according to the engineering and technology principles (Andrienko et al., 2007). Results of our present study addresses these gaps by demonstrating the utilization of our proposed Human Centered GeoVis framework as illustrated in our prior study (Joshi et al., 2012).

Geospatial data exploration and visual analysis can be used to inform public health research, planning and decision-making. Public health organizations are increasingly harnessing geospatial technologies to aid in decision support for a broad range of purposes, including disease surveillance, health services allocation and for targeting health promotion initiatives.

The present study addresses a novel approach of evaluating telehealth programs by using GeoVis applications. The results presented here help to uncover the common telehealth indicator categories, overlapping of some tasks in each of these telehealth indicator categories and the preferences of the various users on how to present the findings of these tasks. Majority of the tasks had spatiotemporal relevance despite having limited prior GeoVis familiarity and prior spatial skills among the various telehealth users. Prior results also demonstrate poor SUS scores for the various existing public health GeoVis applications and so provides considerable evidence and motivation to design and develop GeoVis applications that are easy to use and can effectively facilitate visual exploration of telehealth data.

In summary, the present study helped to illuminate some important considerations for developing GeoVis applications for use by different telehealth stakeholders. Although the users had varying levels of expertise and knowledge of mapping and geo-visualization, the participants were enthusiastic about the use of GeoVis application “The SanaViz”. Future studies are needed to assess the long term use of “The SanaViz” and to determine the changes that might be needed to be made for further improvement of the prototype. Further research is also warranted to examine how the use of GeoVis application in telehealth can improve public health planning and decision making.

References

- Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M. J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, 21(8), 839-857.
- Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human–Computer Interaction*, 24(6), 574-594.
- Bhowmick, T., Griffin, A. L., MacEachren, A. M., Kluhsman, B. C., & Lengerich, E. J. (2008). Informing geospatial toolset design: Understanding the process of cancer data exploration and analysis. *Health & Place*, 14(3), 576-607.

- Bhowmick, T., Robinson, A. C., Gruver, A., MacEachren, A. M., & Lengerich, E. J. (2008). Distributed usability evaluation of the Pennsylvania Cancer Atlas. *International Journal of Health Geographics*, 7(1), 36.
- Brazilian Telehealth Program. (2011). Retrieved from: <http://www.telessaudebrasil.org.br>
- Brooke, J. (1996). SUS-A quick and dirty usability scale. In Jordan PW, Thomas B, Weerdmeester BA, McClelland AL, (Eds.). *Usability Evaluation in Industry*, 189, 194. London: Taylor and Francis.
- Cinnamon, J., Rinner, C., Cusimano, M. D., Marshall, S., Bekele, T., Hernandez, T., Chipman, M. L. (2009). Evaluating web-based static, animated and interactive maps for injury prevention. *Geospatial Health*, 4(1), 3-16.
- Dennis, A. R., & Carte, T. A. (1998). Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations. *Information Systems Research*, 9(2), 194-203.
- Fabrikant, S. (2001). Evaluating the usability of the scale metaphor for querying semantic spaces. In Montello, D.R., (Ed.). *Spatial Information Theory: Foundations of Geographic Information Science*. Berlin: Springer.
- Faiks, A., & Hyland, N. (2000). Gaining user insight: A case study illustrating the card sort technique. *College & Research Libraries*, 61(4), 349-357.
- Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 7(2), 174-196.
- Hu, P. J., & Chau, P. Y. (1999). Physician acceptance of telemedicine technology: An empirical investigation. *Topics in Health Information Management*, 19(4), 20-35.
- Johnson, C. M., Johnson, T. R., & Zhang, J. (2005). A user-centered framework for redesigning health care interfaces. *Journal of Biomedical Informatics*, 38(1), 75-87.
- Joshi, A., Novaes, M. A., Iyengar, S., Machiavelli, J. L., Zhang, J., Vogler, R., & Hsu, C. E. (2011). Evaluation of a teleeducation program in Brazil. *Journal of Telemedicine and Telecare*, 17(7), 341-345.
- Joshi, A., Novaes, M.A., Iyengar, S., Machiavelli, J.L., Zhang, J., Vogler, R., Hsu, C. E. (2012). A human centered geovisualization framework to facilitate visual exploration of telehealth data: a case study. *Technology and Healthcare*.
- Kelsey, B., & Rinner C. (2009) User task scenarios for map-based decision support in community health planning. *Proceedings from the 12th AGILE International Conference on Geographic Information Science*. Hannover, Germany: Springer.

- Knowles, L., Lewis, A., King, D., King, D., & Jones, D. (2008). Disseminating health disparities education through tele-learning. *Journal of Systemics, Cybernetics and Informatics*, 6, 78-82.
- Koua, E. L., & Kraak, M. J. (2004). A usability framework for the design and evaluation of an exploratory geovisualization environment. Proceedings from the 8th International Conference on Information Visualization. London, UK: IEEE Computer Society.
- Koua, E. L., MacEachren, A., & Kraak, M. J. (2006). Evaluating the usability of visualization methods in an exploratory geovisualization environment. *International Journal of Geographical Information Science*, 20(4), 425-448.
- Kushniruk, A. (2002). Evaluation in the design of health information systems: Application of approaches emerging from usability engineering. *Computers in Biology and Medicine*, 32(3), 141-149.
- Kushniruk, A. W., & Patel, V. L. (2004). Cognitive and usability engineering methods for the evaluation of clinical information systems. *Journal of Biomedical Informatics*, 37(1), 56-76.
- Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, 20 (7), 703-726.
- Novaes, M.A., Mattos, S.S., Barbosa, A.K., & Soares, K.A. (2004) Telehealth in northeast Brazil: a pilot program for the public sector. In Fieschi, M., Coiera, E., Li, Y., (Eds.). MEDINFO 2004. Amsterdam: IOS Press.
- RedeNUTES Pernambuco. (2011). Retrieved from: <http://www.redenutes.ufpe.br>
- Reed, K. (2005). Telemedicine: Benefits to advanced practice nursing and the communities they serve. *Journal of the American Academy of Nurse Practitioners*, 17(5), 176-180.
- Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., & MacEachren, A. M. (2005). Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science*, 32(4), 243.
- Shaw, D. (1996). Handbook of usability testing: How to plan, design, and conduct effective tests. *Journal of the American Society for Information Science*, 47(3), 258-259.
- Slocum, T. A., Cliburn, D. C., Feddema, J. J., & Miller, J. R. (2003). Evaluating the usability of a tool for visualizing the uncertainty of the future global water balance. *Cartography and Geographic Information Science*, 30(4), 299-317.
- Sweeney, M., Maguire, M., & Shackel, B. (1993). Evaluating user-computer interaction: A framework. *International Journal of Man-Machine Studies*, 38(4), 689-711.

- Timpka, T., Ölvander, C., & Hallberg, N. (2008). Information system needs in health promotion: A case study of the safe community program using requirements engineering methods. *Health Informatics Journal*, 14(3), 183-193.
- van Elzakker, C. P. J. M. (2003). The use of maps in exploration of geographic data. Proceedings from the 21st International Cartographic Conference (ICC). Durban, South Africa.
- Wassink, I., Kulyk, O., Dijk, B., Veer, G., & Vet, P. (2009). Applying a user-centered approach to interactive visualisation design. *Trends in Interactive Visualization*, 3, 1-25.
- Wehrend, S., & Lewis, C. (1990). A problem-oriented classification of visualization techniques. *Proceedings from the 1st Conference on Visualization'90*, 139-143.
- Zhang, J., & Butler, K. (2007). UFuRT: A work-centered framework and process for design and evaluation of information systems. Proceedings from the 12th International Conference, HCI International 2007. Beijing, China.

RESEARCH SUMMARY

In general, there is limited guidance on how to design GeoVis applications despite its growing importance in healthcare. By researching and applying the methods and processes discussed in the three manuscripts, this dissertation research developed understanding and fills the existing gap in the literature on how to design, develop and evaluate Human Centered GeoVis applications. The research conducted supports the usefulness and effectiveness in utilizing GeoVis applications, as a proof of concept to evaluate telehealth program. Further, this dissertation research developed an informatics category framework using combined principles of Human Centered approach, Cognitive Fit and Grounded Theory to map the needs of the telehealth users, the tasks they perform and the representation of their data in a format that is easy to understand and is effective in performing their tasks.

This research supports the basis definition of biomedical informatics by describing how to transform data into meaningful information and disseminate the information findings in a format that is easy to understand tailored to the needs of the users. In the case of this research, this was achieved through the design, development and evaluation of a GeoVis prototype “The SanaViz” using combined principles of Human Centered approach and Cognitive Fit Theory. This dissertation research addresses the following informatics implications as defined in prior study (Bernstam, VE, Smith WJ and Johnson RT, 2009):

- Informatics: Information Data +Meaning
- Human beings construct meaning by representations
- Understanding how users interact with visual representations

Data Visualization, exploratory data analysis and human factors engineering all play major role in constructing applications that help discover,, understand and use of information

Contribution to Informatics

Knowledge: This research adds a new outlook and understanding about the utilization of GeoVis applications as a proof of concept to facilitate visual exploration of telehealth data.

Theoretical: This research creates an informatics framework of GeoVis using combined principles of Human Centered approach, Cognitive Fit Theory and Grounded Theory.

Practical: This research describes the methodology to implement the framework for the design and development of HC GeoVis applications that are both useful and effective in meeting the needs of the users and the tasks they perform.